The Essential Role of Enzymes

1. Enzymes can help achieve EU Green Deal targets

As of 2019, Europe is the leading producer of enzyme products with AMFEP members, which represent **90% of the European enzymes** market, accounting for around 80% of the global enzymes market. In 2018, Denmark, Finland, Belgium, France and Germany together accounted for 97% of the total volume of enzyme products sold by EU manufacturers, i.e. **284,404 tonnes**[1]. The product value of enzyme products in EU is estimated at **2 billion euros (**AMFEP 2019).

While enzymes are classified as respiratory sensitizers category 1, **their inherent properties precisely make their use 'essential' for protecting the environment and human health from the most harmful chemicals across many industries**. Enzymes are bio-manufactured proteins that offer bio-based solutions and bring a broad range of sustainability benefits. They are used in small amounts (they catalyse chemical reactions and are recycled from one reaction to the next during the same use), reduce energy consumption (as catalysts they lower the energy threshold of chemical reactions), and can replace chemicals harmful to humans and the environment. In other words, one of the main reasons that enzymes are used is that they represent a more benign alternative to the very type of chemicals that the CSS aims to reduce use of.

Enzymes enable a wide range of industries to meet the EU's ambitious sustainability targets and objectives in policies such as the Bioeconomy Strategy, Industrial Strategy, Farm-to-Fork Strategy, Circular Economy Action Plan, and Zero Pollution Action Plan. Enzymes thereby contribute to the Green Deal goals of improving air quality, clean water and healthy soil, healthy and affordable food, cleaner energy, recycled products, whilst also supporting jobs and global competitiveness. Uses, functions and benefits of enzyme uses are summarized in sections 3 to 9 of this document.

2. Enzymes have a long history of safe use

The enzyme, detergent and other sectors over 50 years of experience in the safety of enzymes regarding both occupational and consumer conditions and focusing on product design and guidance to obtain exposures below the respective derived minimal effect levels (DMELs). AMFEP has created, on its own and in collaboration with the downstream users' associations for multiple sectors, publicly available guidance, recorded webinars and posters on the safe use of enzymes and safe products for workers[2] and for consumer products[3].

Industrial enzymes have an excellent safety profile with little ability to cause adverse responses in humans.

Enzymes are unremarkable for acute toxicity, genotoxicity, sub-acute and repeated dose toxicity. Reproductive toxicity and carcinogenicity are not endpoints of concern[4]. The important exception is the intrinsic potential of enzymes to act as respiratory sensitisers, similar to pollen.

Respiratory sensitization due to exposure to enzymes results in the development of IgE antibodies which are completely specific to the specific enzyme in question. Combined exposure to several enzymes will therefore

[1] PRODCOM (2019)
[2] AMFEP - Guide on safe handling of enzymes, SAFE HANDLING OF ENZYMES - AISE,
[3] ACIConsumerEnzymeProductRiskAssessmentGuide.pdf (cleaninginstitute.org), Support by accredited stakeholders - ECHA (europa.eu)
[4] Basketter D et al, Enzymes in cleaning products: An overview of toxicological properties andrisk assessment/management Regulatory Toxicology and Pharmacology 64 (2012) 117–123. http://dx.doi.org/10.1016/j.yrtph.2012.06.016

not lead to a synergistic, additive or antagonistic effect, as IgE antibodies specific for one enzyme will generally not react towards other enzymes.

Sensitisation by itself is not a disease, as there are no symptoms. It is merely an indicator that the person has been exposed via airborne exposure to a high dosage of the specific sensitizer at some point. Repeated exposure to a high dosage of the same enzyme may eventually cause a sensitized person to develop allergy symptoms[5].

DMELs have been set at 60 ng/m3 for workers and at 15 ng/m3 for consumers[6] based on the data generated over decades.

Published data from the detergent industry[7] and the enzyme manufacturing industry[8] shows that controlling airborne exposure using the DMEL as a target leads to a safe working environment with a very limited number of allergies. Incidents of enzyme allergy have only been reported in cases where risk mitigation and the DMEL have not been applied or have failed for technical reasons[9].

Allergy to enzymes among consumers of enzyme-containing laundry and cleaning products has not been reported since the late 1960's. Clinical evidence shows that the prevalence of enzyme specific sensitization in the population is very rare (0.126% in the 1977 –2010 period)[10]. This demonstrates that sensitisation due to exposure to enzymes via laundry and cleaning products is not an issue among the general population.

The following section expands on examples of safe use of enzymes, while illustrating their sustainability benefits in various industrial sectors.

3. The Detergent Industry

Enzymes are used in detergent products to enhance cleaning performance while decreasing environmental impact. They help the breakdown of larger molecules into smaller fragments, that can then be easily removed easily by other ingredients in the formulation. Enzymes provide high performance on stain removal, whiteness, freshness, colour and fabric care from their detergents[11]. A majority of laundry detergents and automatic dishwashing detergents contain enzymes (Table 1).

[5] Basketter et al, Enzymes and sensitization via skin exposure: A critical analysis, Regulatory Toxicology and Pharmacology 129 (2022) 105112

[6] Basketter et al., 2010. Defining occupational and consumer exposure limits for enzyme protein respiratory allergens under REACH. Toxicology 268: 165-170.

[7] Basketter DA, Kruszewski FH, Mathieu S, et al. Managing the Risk of Occupational Allergy in the Enzyme Detergent Industry. J Occup Environ Hyg. 2015;12(7):431-437. doi:10.1080/15459624.2015.1011741

[8] Johnsen C.R., Sorensen T.B., Larsen A.I., Secher A.B., Andreasen E., Kofoed G.S., Nielsen L.F., Gyntelberg F. (1997) Allergy risk in an enzyme producing plant: a retrospective follow up study. Occupational and Environmental Medicine ;54:671-675.
A I Larsen, C R Johnsen, J Frickmann, et al. (2007) Incidence of respiratory sensitisation and allergy to enzymes among employees in an enzyme producing plant and the relation to exposure and host factors. Occup Environ Med;64:763–768. doi: 10.1136/oem.2005.025304.
A. I. Larsen, L. Cederkvist, A M Lykke, P Wagner, C. R. Johnsen, L. K. Poulsen, (2020) Allergy Development in Adulthood: An Occupational Cohort Study of the Manufacturing of Industrial Enzymes. J ALLERGY CLIN IMMUNOL PRACT VOLUME 8, NUMBER 1

[9] Cullinan P., J.M. Harris, A.J. Newman-Taylor et al.: An outbreak of asthma in a modern detergent factory. Lancet 356:1899–1900 (2000).

[10] Sarlo, K., Kirchner, D.B., Troyano, E., Smith, L.A., Carr, G.J., Rodriguez, C., 2010. Assessing the risk of type 1 allergy to enzymes present in laundry and cleaning products: evidence from the clinical data. Toxicology 271, 87-93.

[11] AISE-AMFEP-HCPA-ACI Enzyme Factsheet https://aise.eu/cust/documentrequest.aspx?UID=ecaa311b-701c-4a50-83ea-f66963f04d87

Table 1. The annual market value and implementation of enzymes

	Laundry detergents*	Automatic dishwashing detergents
Enzyme Market value[12]	€9.8 billion	€3.2 billion
Total number of product launches	743 product per year	207 products per year
Products containing enzyme(s) [13]	75%	95%

*) Liquid detergents, Powder detergents, Detergent unit doses

Respiratory sensitisers are generally excluded from the Ecolabel criteria for laundry and cleaning products in EU, however the EU decided that enzymes are derogated from the exclusion because of their contributions to the overall goals of the ecolabels in the following applications:

- **EU Ecolabel:** laundry detergents; dishwasher detergents; industrial and institutional dishwasher detergents; hand dishwashing detergents; industrial and institutional laundry detergents.
- **Nordic Ecolabel:** laundry detergents and stain removers.

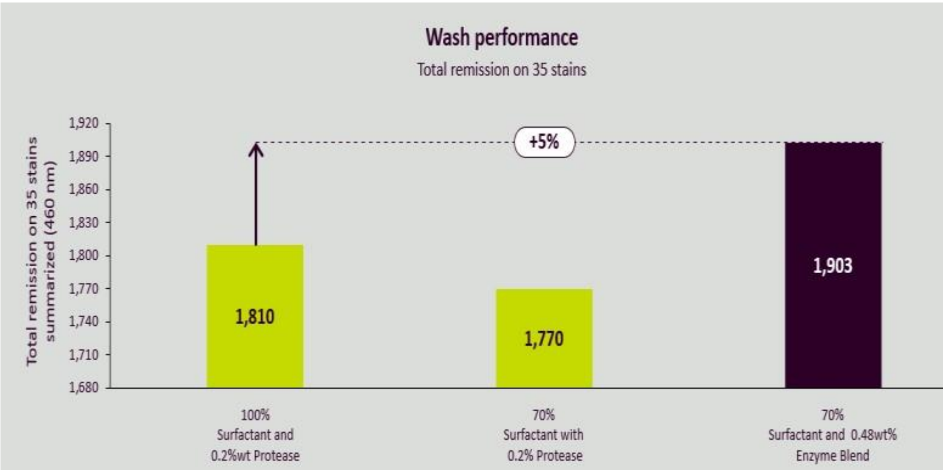


Figure 1. After 30% reduction on surfactants, enzyme products could still deliver 5% performance increase[14]

Enzymes act catalytically, and can repeat their job over and over, resulting in high cleaning activity at very low concentrations, whereas surfactants act by forming micelles and are used up during the wash processes (Figure 1). Therefore, replacing parts of the conventional detergent ingredients by enzymes will result in a reduction of the total amount of detergent required per wash. Cutting down the amount of surfactant by using enzyme based detergent formulations leads to a considerable reduction of CO_2 emissions caused by the manufacturing of detergent ingredients and also in a considerable reduction of the contribution to aquatic toxicity, CDV.

Enzymes are readily biodegradable and their use in detergent formulations significantly contributes to the reduction of energy consumption and CO2 emissions.

Enzymes degrade stains into smaller molecules under mild conditions such as low temperature. For example, lipase is an enzyme degrading oily stain (glycerides) and it can remove oily stains at 20 °C (Figure 2). The washing

[12] AISE 2020. https://www.aise.eu/our-industry/market-and-economic-data-2292.aspx
[13] Mintel (2022). Newly launched products in EU and % products containing enzymes as average of 2019 ~ 2021.
[14] Wash conditions: Top loader, standard cotton wash program 37L, 25°C, 15 min. main wash, 2 rinses, water hardness 14°dH, 1.5 kg ballast, emerging market model liquid detergent (74 ml/wash), Surfactants: 5wt% LAS, 8wt% AEOS, 4wt% AEO, 1wt% soap, Enzyme Blend: Protease, Amylase, Lipase, Mannanase, Cellulase (Novozymes 2021)

performance of detergents at low temperature has been improved with increasing enzyme usage since 1985, while the **average washing temperature in the EU has decreased from 62°C to 41°C**. If the average laundry temperature in Europe decreases by 3°C, it would save 2,300 GWh/year (equivalent to the electricity consumption of more than 300,000 inhabitants)[15].

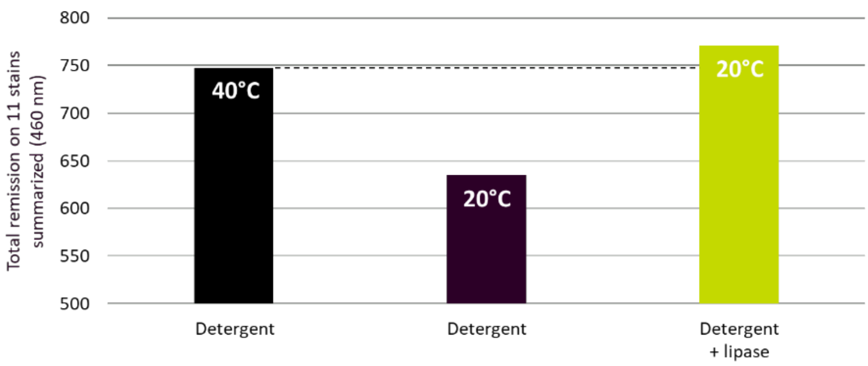


Figure 2 Example on Stain Removal at reduced temperature with Use of Enzymes[16]

One of the main innovations enabled by use of enzymes is the compact detergents products. **Compaction means that the product is, amongst others, more concentrated and the chemical load to the environment is reduced**. **Water use is also reduced** and there are savings in fuel as less product is transported. For example, the average dosage had been reduced by half and the aggregated saving of detergent had been estimated as 30 million tonnes in the period of 1997 and 2017[17]

Two recent studies on enzyme use in laundry detergents show that chemical consumption, greenhouse gas emission and impact on the aquatic environment can be reduced when enzymes replace surfactants in detergents is improved on whilst wash performance is improved and cost of detergent is reduced. (link). See Figure 3 and 4. Similar studies have shown how enzymes can replace polymers and optical brighteners to the benefit of climate and the aquatic environment.

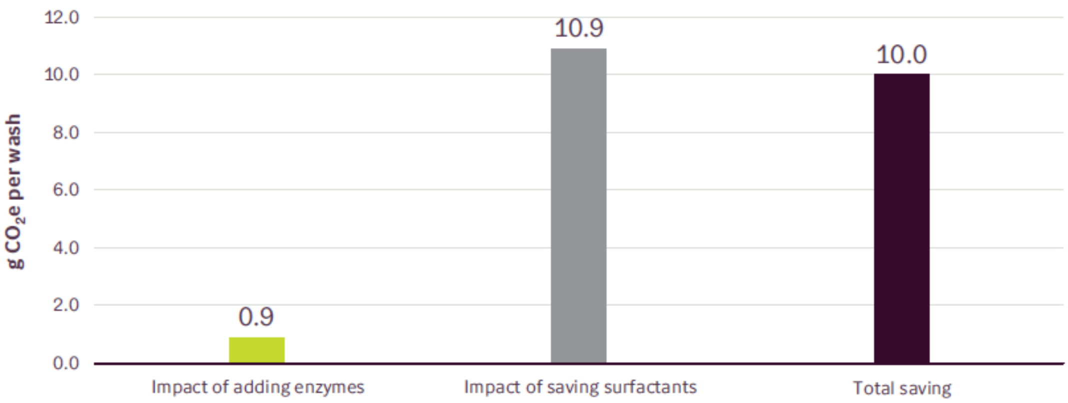


Figure 3: Greenhouse gas emissions (CO2 equivalents) of enzymes and surfactants when surfactant concentration of a conventional detergent is reduced by 30% and replaced by a blend of five enzymes.

---

15 I PREFER 30° https://www.iprefer30.eu/en

16 Wash conditions: EU front loader, standard cotton wash program 20/40°C, 51 min. main wash, water hardness 15°dH, 4 kg ballast,stain set composed of 11 lipase sensitive stains, EU regular liquid detergent (75 ml/wash)

17 A.I.S.E. Fact sheet 2019 20190410111600-aise_factsheet-2019_compaction_def.pdf

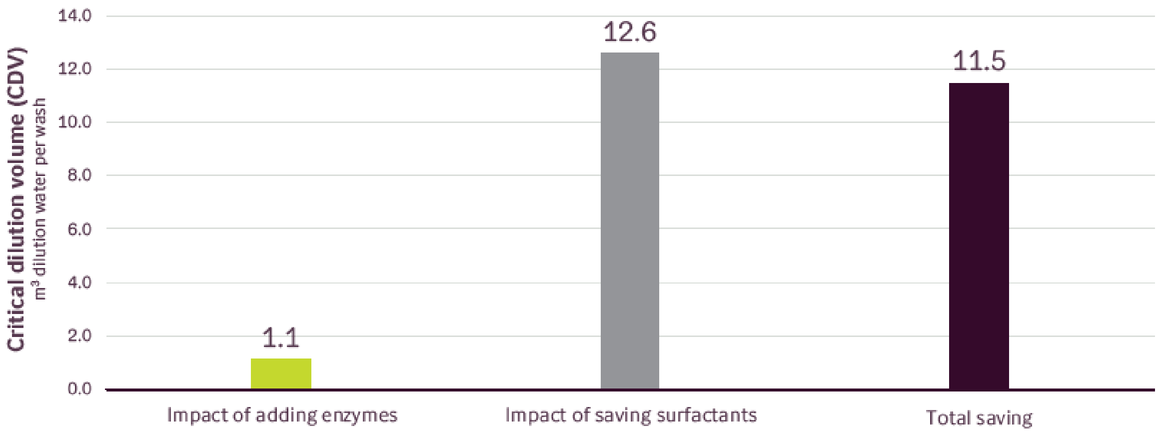
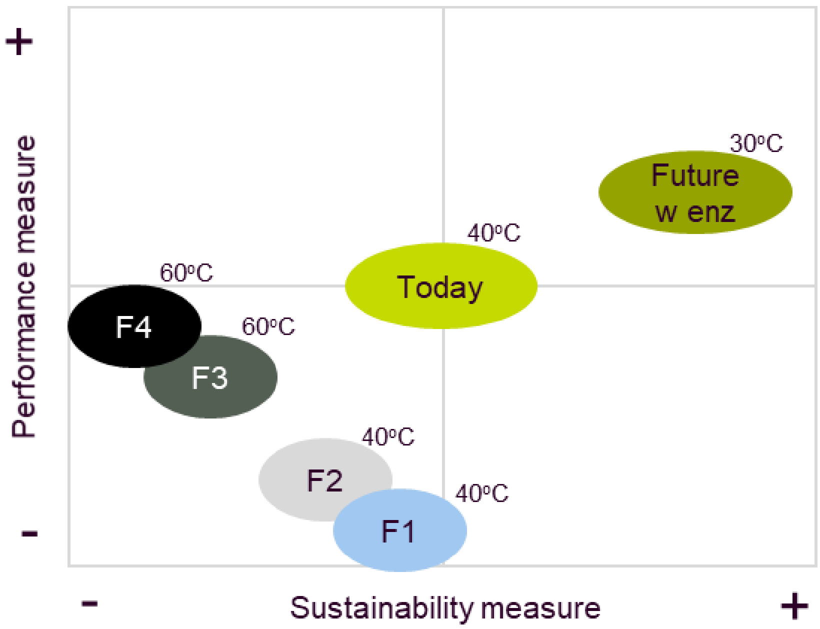


Figure 4: Critical Dilution Volumes (CDV) of enzymes and surfactants when surfactants in a conventional detergent are reduced by 30% and a blend of five enzymes is added. CDV is a theoretical expression of detergent ingredients impact on water living organisms. It takes into account each ingredient's dosage, biodegradation and toxicity. CDV is the volume of water that is needed to dilute substances to a level where they no adverse on water living species.

What if enzymes were removed from detergents?

Various experimental and digital tools are used by enzyme and detergent manufacturers to address cost, performance and environmental impact of detergents when new enzymes are considered for a detergent. These tools have been used reversely to assess what would happen if enzymes were removed from detergents (full documentation in preparation) to give an indication of enzymes importance in detergents.

Figure 5 shows the main results of the assessment and indicates what would happen to the wash performance and environmental impact of laundry washing in various development scenarios relative to today.



+ Best performance

- Worse performance

Figure 5: Indicative illustration of performance versus sustainability of laundry washing in five envisioned scenarios with and without enzymes in laundry detergents relative to today. "Performance measure" is a combination of stain removal, whiteness/colour maintenance, and freshness/hygiene elements. "Sustainability measure" is a combination of impact on lifetime of clothes, climate impact and impact on the aquatic environment. "Future w. enzyme": use of enzyme in detergents develops organically from where we are today (reduction of wash temperature and chemical use).

F1-F4: Four envisioned scenarios on what consumers and detergent manufacturers could do to compensate for loss in wash performance if enzymes disappeared from detergents.

F1: Nothing is done to compensate for the absence of enzymes.

F2: Detergent dose is doubled to compensate.

F3: Laundry wash temperature is increased to compensate

F4: Detergent dose is doubled, and wash temperature is increased.

Figure 5 indicates that there is potential to increase wash performance whilst at the same time reducing the environmental impacts of laundry washing ~~in the future~~ if enzyme technology can develop organically in the future.

Performance drops considerably on the measured parameters when enzymes are removed. It can to some extent be compensated for by increasing chemical dosage per wash and specially increasing wash temperature. Adding more chemicals per wash will increase pressure on the aquatic environment. Increasing wash temperature will increase pressure on the climate.

There is no scenario where the current level of performance or the current level of environmental impact can be matched. Taking away enzymes from detergents will close a pathway towards better performance and lower environmental impact of laundry washing and lead laundry washing into a space where both performance and impact on the environment are worse. The same applies to the cost of detergents to consumers (data not shown) in cases where additional chemical detergents are used. Reduced wash performance can lead to increased re-washes and shorter useful lifetimes of garments and textiles, thus increasing the environmental impact of producing and disposing textiles.

An estimate of the total impacts in Europe of removing enzymes from the detergent formulation is shown in Table 2.

Table 2: Additional electricity consumption and environmental impacts of laundry washing per year in the EU relative to scenario "Today" if enzymes were removed from detergents and consumers and detergent manufacturers compensated for the performance loss, i.e., increased detergent doses and wash temperatures (Scenario F4). Source: In preparation

Impact category	Unit	Quantity
Electricity[1]	Million MWh	12
Greenhouse gas emissions[2)]	Million tonnes CO_2	3.5
Aquatic toxicity[3)]	CDV, billon m^3 dilution water	720
Chemical consumption	tonnes	280,000

1) Includes only electricity for laundry wash water heating, assuming: 15.6 litres wash water per wash and 3.2 washes per household. 2) Includes increase of both wash temperature and chemical consumption, assuming 0.23 kg CO_2/kWh (average for European Union, link), data on detergent ingredients' climate impact: EcoInvent database (link), impact of enzymes climate impact: Nielsen et al., 2007 (link). 3) Based on method and data from European Union Ecolabel (Link). Number of households in EU is assumed to be 195 million (link).

Growth in electricity demand relative to a future with enzyme is equal to installing 160 extra wind power plants of the largest category (14 MW) or keeping three medium sized coal fired power plants (500 MW) going.

Summary:

Enzymes are widely used in detergents and dishwashing products today. Enzymes act catalytically on specific stains and contribute to the high wash performance that is now the norm. Enzymes are used in small amounts in detergents and they contribute to controlling greenhouse gas emissions from detergent manufacturing. Enzymes are readily biodegradable and use of enzymes contribute to controlling pressure on wastewater treatment plants and on the aquatic environment once used wash water is diverted into the drain. Wash-performance would decline considerably if enzymes were removed from detergents. The wash performance gap cannot be closed on all parameters even if chemical use and wash temperatures were increased considerably. Increased chemical consumption and energy consumption for heating wash water to compensate for wash performance loss if enzymes were removed from detergents would increase pressure on climate and the aquatic environment in EU considerably. The additional electricity consumption for wash water heating would correspond to installing 240 big windmills or maintaining five medium-sized coal-fired power plants.

4. The Textile Industry

The textile industry is one of the most polluting industries in the world[18,19] and it has set ambitious goals to improve its sustainability. These include:

- Growing industry commitment to zero discharge of hazardous chemicals and the ongoing search for water saving technologies[20]
- Reducing greenhouse gas emissions by 45% by 2030[21]
- Rampimp up efforts on manufacturing energy efficiency
    - Identifying energy intensive hotspots in different stages of production and make a transition to better practices
    - Scaling up sustainable materials and processes, targeting 39 Mt CO2 reduction22
- Increasing collaboration between brands, suppliers and NGOs
    - Sustainability and circular fashion are on top of the agenda

The use of enzymes in the textile industry has increasingly gained global recognition because of their environmental benefits in various steps of the processing of textiles. Enzyme technology is attractive because enzymes are highly specific and efficient, and work under mild conditions. Furthermore, the **use of enzymes results in reduced process times and energy, water savings and improved product quality**. More specifically, enzymes:

[18] https://doi.org/10.31881/TLR.2020.16
[19] https://ec.europa.eu/commission/presscorner/detail/en/fs_22_2017
[20] Roadmap To Zero - About
[21] FASHION INDUSTRY TRADE POLICY REQUEST| COP26 - Textile Exchange
[22] https://doi.org/10.46830/wriwp.20.00004

- Save up to 30% water use: enzymes speed up processes and significantly reduce water use
- Replace up to 80% of hazardous chemicals used by the industry (for example formaldehyde or hydrogen peroxide). In addition, enzymes are readily biodegradable
- Reduce CO_2 emissions as enzymes can work at room temperature, thereby don't need high temperatures to perform
- Reduce textile waste as enzymatic treatment allows garments to look 'new' longer

These are all valuable process improvements which are enabling the textile industry to improve its overall environmental impact. **Enzymes have therefore been enabling the transition of the textiles industry towards becoming more aligned with the EU policy objectives under the Green Deal, and more specifically of the recent proposal for a [Sustainable and Circular Textiles Strategy](#)** in which the Commission is seeking to "reduce adverse impacts on climate & the environment" by reducing the use of chemicals of concern, among others.

Enzymes are essential in various applications in the textile industry, delivering important benefits, as summarised in Table 2.

Table 3: Examples of Enzyme classes and corresponding functionalities in the textile industry supply chain.

Application	Process step	Enzyme Benefit	Enzyme classes
	Textile pre-treatment		
Starch removal	Desizing	Reduction of hazardous chemicals like peroxides or persulfates; gentle treatment of the woven fabrics	Amylases
Pectin and protein removal (bio-scouring)	Scouring	Bio-scouring Less resources Reduced energy use, chemical use (e.g. caustic soda (NaOH) in cotton processes or chlorine in wool processes) water and time; less wastewater; gentle treatment of the woven fabrics	Pectinases & Lipases in some cases (vegetable fibres) Proteases (wool, silk) Xylanase (linen, jute, hemp)
Carboxy methyl cellulose (CMC) size removal	Desizing	Avoidance of hazardous chemicals like acids or persulfates; gentle treatment of the woven fabrics	Amylases Cellulases
Degradation of excess hydrogen peroxide after bleaching	Peroxide removal	Avoidance of hazardous chemicals like sulphur based reducing agents, saving of 1 or 2 wash cycles, safe of energy, water and time, reduce wastewater	Catalases
	Textile/Garment finishing		
Hairiness elimination, pilling reduction, surface cleaning and antifelting finishing	Finishing either as fabric form or garment	Saving energy, water and time; less wastewater; avoidance of hazardous substances and softer handle effect	Cellulases; Proteases
Bleaching of indigo dyed garment articles; Garment finishing	Denim bleaching	Avoidance of hazardous chemicals like various chlorinated compounds, gentle treatment of the woven fabrics, less polluting garment wash	Laccases

Bleaching of cotton	Cotton bleaching	Saving energy, reduced cotton loss from fabric, water savings	Arylesterase
Denim finishing, biostoning	Garment finishing	Avoidance of sandblasting and/or the use of pumice stones, gentle treatment of the material	Cellulases
	Other processes		
Post-textile treatment process: Decolorization of textile effluents and textile bleaching	Wastewater treatment plants	Avoidance of hazardous chemicals	Laccases

***Conclusion*:**

For the textiles industry, banning the use of enzymes would be a step backwards in terms of human health protection and environmental benefits achieved over the course of several decades for the industry.

5. The Pulp and Paper Industry

For decades, enzymes have been widely used in the pulp & paper industry due to their unique properties that facilitate the production of high-quality pulp & paper products and, at the same time, have progressively reduced the use of chemicals in the industry – thereby significantly improving the ecological footprint of the sector and of the final products. In this way, **enzymes have in fact been enabling the transition of the pulp & paper industry towards becoming more aligned with the EU policy objectives of the Green Deal, CSS, and of promoting sustainable products.**

The pulp & paper industry is a very innovative industry as new applications for pulp & paper products are being developed continuously. While paper use is decreasing in certain sectors such as print media, its use is increasingly becoming attractive for other applications such as packaging. In addition, the raw material used by industry is sustainable, since it is either sourced from wood coming from sustainably grown forests, or from recycled paper. The majority of European paper and paper-based packaging materialsis recycled[23]. **Enzymes contribute to the significant reduction of electricity used in the process, the CO_2 released and the use of hazardous chemicals[24].**

Enzymes are essential in various applications in the pulp & paper industry, delivering important benefits. This is summarized in Table 3 and in the section below.

Table 4: Examples of enzyme uses in the pulp & paper industry and their benefits

No	Application	Segment	Enzyme Benefit	Enzyme
1	Fibre modification	Chemical pulp & recycled paper	**Efficient process**: Improved drainage, improved productivity, material mix optimisation, vessel element mitigation,	Cellulase

[23] Sustainability & Circularity | www.cepi.org

[24] Sakes, P. B., Krabek, A., Nielsen, P. H., & Wenzel, H. (2008). Environmental Assessment of Enzyme Assisted Processing in Pulp and Paper Industry. Int J LCA, 13(2).

			Better products: improved paper strength, reduced fibre use (fewer wood resources), reduced paper weight, **Less resources**: optimized use of wood resources, and of recycled paper; reduced use of energy and of chemicals, Reduction of electricity • 160 kWh/ton-pulp Reduction of CO_2 • 145kg/ton-pulp	
2	Bio-bleaching virgin fibre	Chemical pulp	Reduced use of bleaching chemicals and consequential reduction of AOX* in effluents, better use of wood resources with a higher wood yield and reduces use of water in the process Reduction of chemicals: • NaOH (50%): 9.6 kg/ton-pulp • ClO_2: 3.7 kg/ton-pulp Reduction of CO_2 • 37 kg/ton-pulp	Xylanase
3	Pulp specifications	Chemical pulp	Degree of polymerisation reduction Reduction: • pentosan, extractives, mannan	Cellulase, Xylanase, Lipase, Esterase, Mannanase
4	Anionic trash removal (TMP, BCTMP**)	Mechanical pulp	Enhances the effectiveness of functional additives	Pectinase
5	Chips and Rejects refining (TMP, BCTMP)	Mechanical pulp	Reduced use of energy Reduction of electricity • 11.4 kWh/ton-paper Reduction of CO_2 • 145 kg/ton-pulp	Cellulase, Lipase, Esterase, Xylanase, Mannanase
6	Bio-bleaching TMP and recycled pulp	Mechanical and recycled paper	Reduced Peroxide use	Catalase
7	Pitch, stickies, and deposit control	Sulphite, Mechanical and recycled paper	Resin removal; boil-outs, improved processability of recycled paper; reduced cleaning chemicals Reduction of chemical: • Cleaning agent: 0.07 kg/ton-paper (Pitch control) • Talc: 3.5 kg/ton-paper (Pitch control) • Solvent: 0.025 kg/ton-paper (Stickie control) • Talc: 1.5 kg/ton-paper (Stickie control) Reduction of electricity • 11.4 kWh/ton-paper (pitch control)	Lipase, Esterase, Protease

			• 9.8 kWh/ton-paper (Stickie control) Reduction of CO_2 • 8.7 kg/ton-pulp (pitch control) • 13kg/ton-pulp (stickies control)	
8	Pulping and deinking	Recycled paper	Reduced energy use, improved fibre strength, reduced use of deinking chemicals, higher use of lower quality recycled paper Reduction of chemicals: • NaOH (50%): 8.56 kg/ton-pulp • NaHSO3: 2.6 kg/ton-pulp • Urea: 0.54 kg/ton-pulp • H2O2: 3.7 kg/ton-pulp • Talc: 5.8 kg/ton-pulp • Retention aid: 1.1 kg/ton-pulp Increase of chemicals apart from enzymes • ClO2: 0.68 kg/ton-pulp • Alun: 0.65 kg/ton-pulp Reduction of CO_2 • 6.4 kg/ton-pulp	Cellulase, Lipase, Esterase, Amylase
9	Starch modification	Paper	Reduced viscosity	Amylase

*Absorbable organic halogenated compounds

**Thermo-mechanical pulp

Conclusion:

For the pulp and paper industry, banning the use of enzymes would be a step backwards in terms of human health protection and environmental benefits achieved over the course of several decades for the industry because there are no alternatives to enzymes[25].

6. The Grain and Starch Processing Industry

This industry processes starch-containing raw materials like maize, wheat and potatoes into starch, proteins and fibers. The starch can be sold as such or modified. Using enzymes, starch can also be transformed into sugars, dextrins and polyols. The end products are used in a variety of downstream applications, particularly food but also feed and other industrial applications.

The European grain and starch processing industry transforms 25 million tonnes of agricultural raw materials from 60,000 European farmers into 11 million tonnes of starch and derivatives, and 5 million tonnes of proteins and fibers. More than 50% of the starch are transformed into sweetener[26].

[25] Skals, P. et al. Environmental Assessment of Enzyme Assisted Processing in Pulp and Paper Industry. Int. J. LCA 13(2) 124-132 (2008)
[26] Source: Starch Europe (https://starch.eu/)

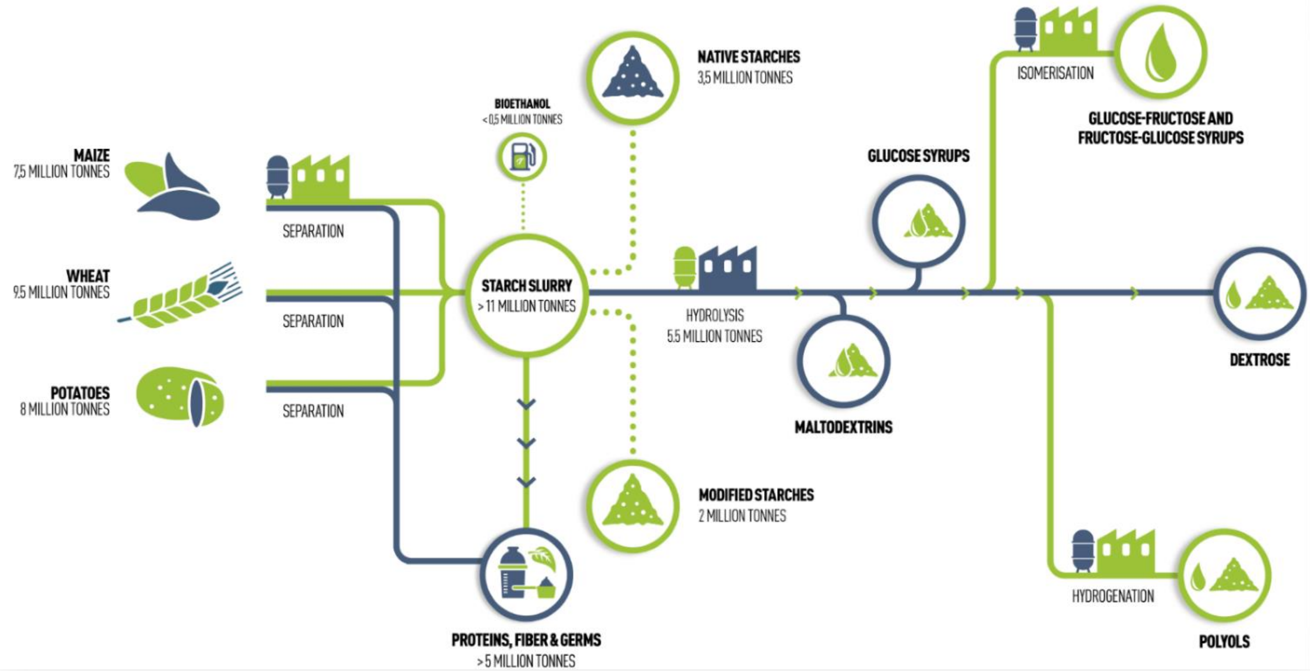


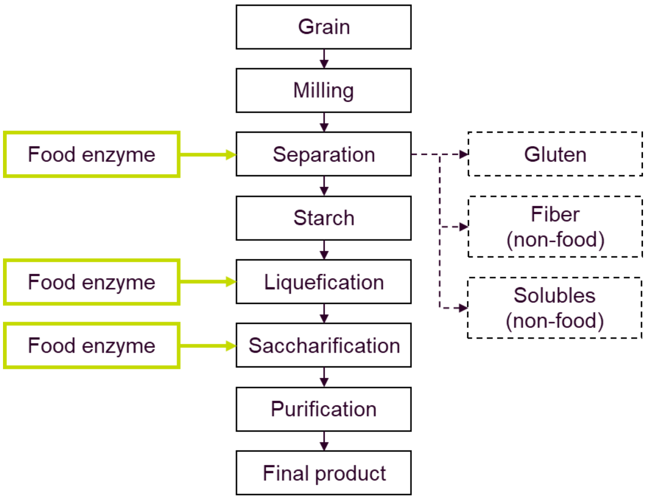
Figure 6: the grain and starch value chain

Use of enzymes in the processes

The industrial production of glucose syrups from maize started in the second half of the 19th century in the USA, based on acid hydrolysis of starch into glucose.

The first use of an enzyme in industrial glucose syrup production occurred in 1938. In the 1970s, alpha-amylases capable of liquefying starch at more than 100°C became available from enzyme producers. Hence, processes were soon developed for producing glucose syrups by enzymatic hydrolysis of starch. The high purity of glucose syrup obtained with enzymes is critical especially for uses such as medical use e.g. intravenous drip and fermentation for citric acid. High maltose syrups containing between 50 and 90% w/w maltose could also be produced. Further developments in enzyme technology allowed the industry to develop ranges of final products that are tailored to the needs of particular customer industries, e.g., in food. This includes polyols such as maltitol-containing syrups, which have found use in low cariogenic calorigenic confectionery.

A typical enzymatic “grain to end product” process can today be schematised as follows:



Grains are milled and subsequently separated in gluten/protein, fiber and starch fractions. The starch fraction is then liquefied into maltodextrins. The saccharification step transforms these molecules into a wide range of products, including, but not limited, syrups (glucose, high fructose, high conversion, maltose).

N.B.: the above process flow is only a general case, more specific processes can be applied for the production of certain end products (e.g. maltodextrins).

Today, the liquefaction part of the process can in principle be performed with either enzymes or acid, however acid liquefaction is to date practically not used (acid is less and less used). Acid hydrolysis liquefaction has strong limitations, as the carbohydrate spectrum that can be obtained is limited, as is the amount of reducing sugars (DE, or dextrose equivalent). It exposes workers to harsh chemicals, increases the need for pH correction and ion-exchange purification, demands significantly more energy (higher temperatures such as 140°C), generates more waste and creates more maintenance costs.

Enzymes are therefore now used in most steps of the process, leading to technical and environmental benefits as well as to a wide range of different products. These examples are listed in the below table:

Table 5: examples of applications of enzymes and related benefits in grain and starch processessing

Application	**Process step**	**Enzyme benefits**	**Enzyme class exampleses**
Degradation of the grain structure, breaking down the fiber network to release starch and protein fractions	Grain milling and separation	Increased starch yield and purity / reduced cereal, water and energy input Cleaner non-starch fractions (protein and fiber) Reduced drying needs / reduced energy consumption Reduced waste	Xylanase Arabinofuranosidase Cellulase

Transformation of the starch macromolecules into smaller molecules	Liquefaction	Avoidance of harsh chemicals (acid) / no need for acid-resistant equipment / enhanced worker safety (compared to acid-based process) No need for extensive pH neutralization / reduced load at the ion exchange step High flexibility in process conditions (pH, temperature) Very wide range of final products / stability, purity and quality of the syrups	Alpha-amylase
Extensive conversion of the liquefied starch into sugars	Saccharification	High yield and purity Specific cleavage of bonds in amylose and amylopectin Very wide range of final products	Alpha-amylase Beta-amylase Glucoamylase Pullulanase Maltogenic amylase
Removal of insoluble particles form syrups	Saccharification	Speeding up filtration / improving yield and purity Improve syrups' clarity	Lysophospholipase
Converting glucose into a mixture of glucose and fructose	Isomerization	High yield and purity Increased sweetness	Glucose isomerase

Products of the Grain and Starch processing industry

Non-exhaustive, indicative list of product types:

- Maltodextrins: non-sweet glucose polymers.
- Glucose syrups: sweet syrups.
- High conversion syrups: sweet syrups containing significant amounts of glucose and maltose together.
- High fructose syrups: sweet syrups containing almost equivalent amounts of glucose and fructose.
- Maltose syrups: sweet syrups with high maltose contents.
- Sugar alcohols: sweeteners obtained from conversion of syrups by hydrogenation.
- Fibers: from the separation step during grain processing.
- Proteins: from the separation step during grain processing.

Products of the Grain and Starch processing industry are used as ingredients in thousands of products in a variety of Food industries[2], where they have a number of nutritional and technological functions. This notably includes:

- Jam, jellies and fruit preserves
- Deep-frozen foods
- Instant soups and sauces
- Meat and fish products

- Beverages
- Bakery products
- Confectionery & chocolates
- Desserts & dairy products

Conclusion: **enzymes are essential in Grain and Starch processing and for its customers**

Enzymes have been used since the 1930s at various stages of grain and starch processing, substituting harsh chemicals, saving energy and water, increasing yields and product quality, and allowing innovation in processes and product ranges.

Enzyme-based processes, when compared to acid hydrolysis of starch, improve workers' safety, reduce the need for ion-exchange purification of syrups, reduce the need for high-performance acid-resistant equipment, thereby increasing the durability of production facilities.

Enzymes have become an essential part of the grain and starch processing industry, to the point where this industry would not be able to revert to decades-old less performing alternative, chemical-based processes. The more than 70 plants (EU 27) that process raw materials and starch are largely built around enzyme-based processes.

Products (range and purity) of the grain and starch processing industry are themselves essential for all of the food industries, to the point where these industries could not revert to the very limited range of ingredients that were~~as~~ available decades ago.

The essentiality of grain and starch processing enzymes is therefore based on sustainability, social, economic, and consumer choice aspects.

Banning enzymes in these industries would have a huge economic impact on the starch industry itself (rebuilding production facilities), but it would also lead to the phase out of a number starch-derived products in EU (which cannot be produced without enzymes), ultimately affecting the Farm to Fork policy.

7. The baking Industry

The continued use of enzymes can be considered 'essential' to the baking sector due to the broad range of sustainability benefits that they have brought for many decades and the lack of alternatives matching enzymes' minimal environment impact, while improving performance.

The essential role of enzymes in the modern baking industry

For centuries, enzymes have acted as natural catalysts to help bakers get the best from their raw materials. Industrial enzymes have been widely used in the baking industry due to their unique properties that facilitate the production of consistent high-quality, healthy, great-tasting baking products, thus ensuring better food for everyone.

For instance, the use of enzymes contributes to facilitating the handling of the dough, improving the dough structure and behaviour during the baking step, and ensuring its machinability, among other benefits. Besides being essential to the overall baking process improvement per se, the use of enzymes also leads to better characteristics of the final bakery products (e.g. volume, crumb structure, firmness and colour, staling, etc), which might otherwise be impaired by the processing of the dough.

In addition, those improved process efficiency and products characteristics, e.g. when the use of certain enzymes shortens the process time and/or makes sure the bread stays soft and moist along its full shelf-life, significantly reduce the ecological footprint of the sector and provide bakers and consumers with products that use less energy, water and raw materials and generate less waste (bread often tops the list of avoidable food waste).

The baking industry is a well-established but innovative industry, especially when it is about sustainability improvement. Baking enzymes can considerably increase both the efficiency and sustainability of the baking production process. They guarantee the same baking result at lower temperatures so reducing energy consumption and costs. They also enable producers to reduce ingredient costs by making ingredients such as emulsifiers and gluten redundant. In addition, enzymes reduce logistics burden by improving freshness so that transportation is needed less often. Moreover, the use of enzymes can result in less food waste as bakery products remain edible for longer. Table 5 provides

In conclusion, the use of enzymes in baking offers a host of advantages that benefit the industry, the society and the environment.

Table 6: non-exhaustive list of enzyme classes used in the baking industry and associated sustainability benefits. Some of them are described in more details below.

Enzyme class	Contribution	Sustainability benefits
Fungal alpha-amylase	Flour correction: ensures desired end-product characteristics such as volume, crust colour, and crumb structure	Higher quality final products
Lipase	Improves crumb structure and crumb colour	Higher quality final products, Less waste during production
Phospholipase	Improves dough strength and stability, loaf volume and crumb softness	Higher quality final products, Less waste during production
Xylanase	Improves dough stability, bread appearance and texture, superior volume of baked goods	Higher quality final products
Glucose oxidase	Improves gluten strengthening	Higher quality final products, Less waste during production
Amyloglucosidase	Improves bread crust colour and bread volume	Higher quality final products, reduced baking times
Maltogenic amylase (1)	Improves moistness, softness and texture of baked goods	Higher quality of final product Reduction of energy consumption, raw materials as well as food waste
Protease (2)	Reduces the strength of flour protein, thereby reducing mix time and elasticity and increasing the extensibility and softness of the dough.	Reduction of energy and water consumption, as well as food waste Higher quality final products

Cellulase	Improves dough conditioning and nutritional profile in whole wheat or whole grain breads	Higher quality final products
Asparaginase (3)	Reduced acrylamide formation	Healthier final products

1. ***Example of maltogenic amylase in white bread:***

When the bread is removed from the oven, a series of changes start. All undesirable changes that do occur upon storage together are called staling. Staling is a highly complex phenomenon with firming being the most well-known and important symptom. Amylases can be added to the dough to degrade damaged starch, which are fermented by the yeast, before bread making, resulting in reduced staling. Doubling this one specific enzyme use will result in keeping white bread fresh for 3 more days, lowering the disposal rate of old bread from 24 to 19%, reduction of 20kg of CO_2e from the end-of-life phase of the bread[2].
Besides reducing the waste of food, there's carbon saving from reducing this waste, as food in landfills contributes to greenhouse gases, as well as reduced need for (plastic) packaging and transport.

2. ***Example of protease in wafers:***

Wafer batter contains a lot of water, which needs to be removed during the baking. An important part of the dough relaxation needed before baking can be achieved with sodium sulfite, which may no longer be used in many countries. A better alternative is the use of proteases. The use of proteases can result in lowering water content in cookie dough or wafer batter by 10%. With this reduced water content, the baking time in the oven can be significantly shortened, reducing energy consumption as well as water consumption. Moreover, the lower water content results in the batter becoming more homogenous and easier to handle. This results in less breakage and stickiness, and thereby in less food waste during the production process. Finally, these enzymes have positive effects quality factors of the final product such as moisture and crispiness, resulting in fewer final products being discarded.

3. ***Example of asparaginase for acrylamide reduction***

Acrylamide is an unwanted substance that can be formed in multiple starch-based foods when heated, due to the natural presence of certain sugars and amino acids. Both the EU and the US FDA warn of acrylamide's possible carcinogenic effects. Various studies have demonstrated that most traditional bread types do not lead to concerning levels of acrylamide and stay well below the recommended thresholds as defined by the European Food Safety Authority (EFSA). However, these studies found that low moisture bakery products in particular - such as biscuits, crackers, crisp bread, wafers and similar - can form levels of acrylamide above the recommended threshold levels. Enzymes enable reduced acrylamide formation in those affected baked goods and other foods by up to 95 percent without compromising on taste, texture, flavour or smell. Enzymes offer a natural solution to healthier baking and also an answer to acrylamide challenges in specific baked goods.

***Conclusion**:*

As the EU focusses on minimising waste and protecting human health and the environment by phasing out the most harmful chemicals in non-essential uses and thereby preventing potential human environmental exposure[27] the use of enzymes in the baking industry is a successful example of the critical role played by enzymes to meet the EU's increasingly ambitious environmental objectives. Leveraging their biological

[27] Wood E&IS GmbH, 'Targeted' stakeholder consultation - Study supporting the Commission in developing an essential use concept in chemicals legislation, 13 April 2022

properties, enzymes are enabling many industries such as the baking sector in their transition towards a Circular Bioeconomy and becoming Taxonomy-compliant – which are other strategic priorities for the EU.
Policies impacting enzymes therefore need to be assessed together, to ensure that limiting their use under one policy ambition does not kill their essential contribution to another one.
For the baking industry, banning the use of enzymes would be a step backwards in terms of human health protection and environmental benefits achieved over the course of several decades for the industry.

8. The dairy processing industry

The continued use of enzymes in the dairy sector should be considered due to their lack of alternatives for the manufacture of certain good and the broad range of sustainability benefits that they enable.
Cheese production, whey processing and lactose reduction and nature sweetening provide concrete examples to that effect.

The essential role of enzymes in modern dairy processing

Cheese production

The use of enzymes in the preservation of milk and therefore reduction of food waste dates back over 3000 years to the ancient Egyptians who preserved milk in animal stomachs. Only later it was discovered that the milk clotting was a function of enzymes. Since this discovery, enzymes have been developed to improve the cheese making process and produce tasty, nutritious and safe products preventing food waste in a sustainable way. Europeans love their cheese. Every year, approximately nine million tonnes of cheese are consumed in the EU and with a value of 30 billion euros the cheese market is of high value to the European economy.

Initially, animal derived enzymes were used to produce cheese in a hygienic and efficient way on industrial scale. Some of these enzymes are still required by law for the production of certain types of cheese like Dutch, French and Italian cheeses. Later, fermentation produced enzyme have been developed that enable the production of vegetarian and organic cheeses and further contribute to the world's sustainable food production. Latest developments contribute to ~~better tasting~~a wider range intasts for cheese and more efficient and sustainable cheese production, resulting in more cheese per litre milk and less loss upon slicing and shredding.

Milk clotting can take place without enzymes, using a highly energy intensive filtration process. The result resembles cheese but is of a much lower quality. Use of enzymes is an important element in reducing the carbon print of cheese production.
Besides the milk clothing enzymes Other enzymes used in cheese production are lipases and lysozyme. Lipase is used to generate piquant taste notes in specific cheeses such as provolone. The alternative is to let this happen by natural fermentation. However, this involves a high risk of spoilage and, subsequently, increased food safety risk.
Lysozyme is added to the immature cheese to protect the cheese in the cheese ripening process fro~~r~~m the production of off-flavours, formation of splits and cracks and the growth of spoilage micro-organisms including *Clostridia*. It has been approved as an additive for many years, showing its essential use in cheese ripening contributing to cheese quality and so preventing food loss.

Whey processing

Whey is a side stream of the cheese production which potentially has high value due to its broad usage possibilities. However, off flavour and color limit these possibilities. Proteases are used to treat whey proteins that are used in infant, sports and medical nutrition. The enzymes will predigest milk proteins, making them more easily digestible and more delicious for infants, patients and athletes. Creating the right flavour note without the use of enzymes is virtually impossible, as is the generation of a perfectly designed whey hydrolysate for infant nutrition products.

During the production of certain cheeses, such as Cheddar, the food colouring annatto is used. As a result, the whey gets an undesirable orange-yellowish colour. The color can be removed with the help of peroxidases. There are other methods to remove the colour mostly involving high amounts of hydrogen peroxide. Next to the fact that this is not allowed in the EU, it is also environmentally unfriendly. Peroxidases work efficiently at room temperature and only small amounts of hydrogen peroxide are needed, which is converted into water as a result of the enzymatic reaction. In that way the whey is decolored in a sustainable way, creating higher value and more possibilities to use the whey, preventing the loss of valuable and nutritious whey proteins.

Lactose reduction and natural sweetening

While milk is a highly nutritious staple food, it is not accessible to a large part of the population. For example in Europe up to 56% of the Italian people suffer from lactose intolerance caused by the lack of lactase production. For them consumption of dairy products generates health issues resulting in the inability to consume a nutritious and healthy food product. The lack of lactase can easily be compensated by adding natural lactase enzymes to the diet or by pretreating dairy products with lactase. Lactase treatment of dairy products converts milk sugar (lactose) that is difficult to digest, into types of sugar that are easily digestible. Alternatively, lactose could be removed by an energy extensive filtration technology.

A beneficial by-effect of the use of lactase in the increased sweeteness of the sugars resulting from the hydrolysis of lactose. So by using lactase, the amount of added sugar in final food products can be reduced or even abandoned resulting in healthier products.

Thus, lactase helps to make nutritious and healthy dairy products available to a large adult population all over the world, which is fully in support of United Nations Sustainable Development Goal (UN SDG) no. 12.

Table 7: Overview of main enzymes used in dairy processing

Enzyme class	Products	Enzyme contribution	Sustainable benefits
Animal rennet, chymosin, pepsin, mucorpepsin	Cheeses and fermented dairy products	· Increased storability and transportability of milk in the form of cheese · Manufacturing of high nutritional product · Increased flexibility in the choice of raw materials · Better controlled protein network resulting in better resistance to the process operations units · Faster and more predictable milk clotting process · Facilitating centrifugation (less raw material losses) with separator · Less product variation and more consistent characteristics of food	Optimal use of raw materials Optimal yields of the final product Reduction of energy and water consumption Reduction of food waste Higher quality final products Increased availability of healthy food

		· Improved organoleptic properties · Improved viscosity and texture facilitating further processing · Increased variety in final products	
Peroxidase	Whey processing	· Efficient removal of whey color	Reduction of food waste Optimal use of raw materials
Lipase	Cheese	·Typical flavour development in different cheese types: Romano, Provolone, Parmesan Feta, Manchego, Blue cheese and etc. · Ensure a uniform flavour of the cheese by mitigation the variations in raw materials. · Accelerated cheese ripening step thereby shortening the process time. · Creation of complete and authentic flavour profile.	Optimal use of raw materials resulting in optimal yields of the final product Reduction of energy and water consumption
Protease	Cheese Fermented milk products Enzyme modified cheese Whey containing foods, infant, sports and medical nutrition	· Improved flavor of cheese, whey, fermented milk products and enzyme modified cheese · Increased process and product consistency · Improved organoleptic quality and intensity · Increased digestibility	Optimal use of raw materials Optimal yields of the final product Manufacturing of essential food
Lactase	Milk, milk derived products incl. ice, fermented milk products Whey containing foods, infant, sports and medical nutrition	·Lactose reduced dairy products for lactose intolerant population ·Improved digestibility of hydrolyzed dairy products ·Improved sweet taste of hydrolyzed dairy products ·Lowered crystallization of frozen products ·Production of whey syrup to be used as a sweetener	Optimal use of raw materials Optimal yields of the final product Manufacturing of essential food Contributing to a healthier lifestyle Increased availability of healthy food

Lysozyme	Cheese	·Contributing to the right organoleptic quality of cheese ·Contributing to physical stability of the cheese ·Prevent growth of gram-positive bacteria including, but not limited to lactic acid bacteria and the genus *Clostridium*	Reduction of food loss

Conclusion:

The use of enzymes in the dairy industry results in a green and sustainable production method of essential food products that would not exist without the use of enzymes. The use of enzymes helps to reduce the dairy sector's carbon footprint and CO2 emissions by producing dairy products efficiently with minimal energy requirements. Furthermore, and most importantly, enzymes help the dairy industry to produce nutritious, healthy and great-tasting food products that are essential foods in the European diet.

9. The animal feed industry – the example of phytase

Phytase (6-phytase EC 3.1.3.26, 3-Phytase EC 3.1.3.8) is an enzyme that hydrolyses phytate. The enzyme is used to release existing phosphorus in animal feed for poultry, swine and aquaculture. In this wayphytase does not only increase the digestibility, but also decreases the release of phytate bound phosphorus into the environment via livestock manure.

Phosphorus is an important macronutrient for animal growth and has been usually added in form of inorganic phosphorus to animal feed in intensive livestock production. A considerable part of the phosphorus that occurs naturally in feed ingredients of plant origin , is bound in form of phytate. The of this phytate bound phosporus in monogastric animals is poor (Table 7). Therefore, phytate bound phosphorus is not absorbed by the animal and largely excreted into manure .

- ✓ Low availability of P in poultry and swine
- ✓ Causes high P excretion in feces as phytate

Table 8: Amounts and estimated availability of P in selected feed materials for poultry feed, International Plant Nutrition Institute (1999)[28]

	Corn	Barley	Wheat	Soya bean meal	De-Hulled Canola meal
P content (%)	0,28	0,36	0,37	0,65	1,01
P availability (%)	16	37	46	38	30

[28] Nagaraju RK, Nielsen PH (2011). Environmental advantages of phytase over inorganic phosphate in poultry feed. Poultry Punch 27, 57-58.

This poor availability of phosphorus from plant feedstuffs results not only in the nutrition enrichment in water environment but also in the requirement of a large amount of inorganic phosphorus supplements, which are produced from natural phosphate rocks in an energy consuming process. Phosphate is essential to plant production and phosphate rock needs to be preserved to ensure high output of agriculture in the future.

- ✓ Phosphate rocks are limited resource
- ✓ A small amount of phytase product can replace a large amount of inorganic supplement

Conventionally high-quality inorganic phosphates such as mono calcium phosphate (MCP) and di-calcium phosphate that offer a high total phosphorus content and excellent digestibility are widely used as supplemental phosphorus. However, the outcome of life cycle assessment (LCA)[29] shows that a large amount of MCP can be replaced by a small amount of phytase. An LCA is used to calculate the environmental impact of phytase and MCP from raw material extraction up to the disposal of the product (in the manure form) on the basis of weight, respectively, and has calculated that 0.15 Kg phytase displaces 6.35 kg MCP in one tonne of poultry feed (Figure 1). More recent work has demonstrated the practical ability to fully replace all inorganic phosphate in broiler diets through the use of phytase[30]. Likewise inorganic phosphate free diets in swine production have also been demonstrated using practical diets[31].

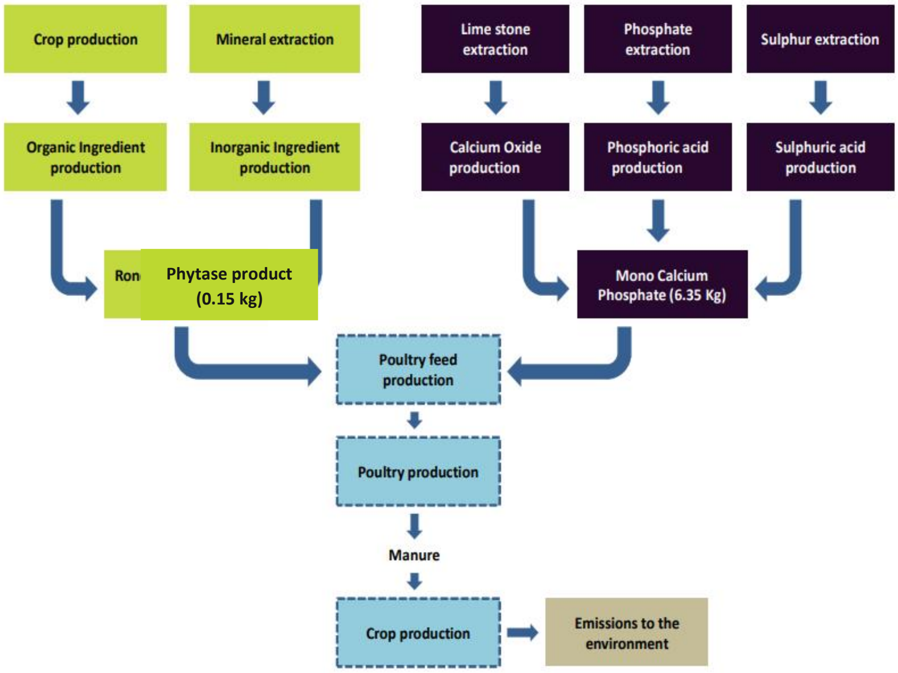


Figure 7: Comparison of production process in poultry [1]. Purple boxes (right) indicate the production process using inorganic phosphorous (MCP) supplementation and green boxes (left) indicates the production process where a phytase product displaces MCP supplementation. Dotted boxes are unchanged with phytase

[29] Ibid.

[30] Marchal L, Bello A, Sobotik EB, Archer G, Dersjant-Li Y (2021) A novel consensus bacterial 6-phytase variant completely replaced inorganic phosphate in broiler diets, maintaining growth performance and bone quality: data from two independent trials. Poult Sci 100, 100962

[31] rsjant-Li Y, Villca B, Sewalt V, de Kreij A, Marchal L, Velayudhan DE, Sorg RA, Christensen T, Mejldal R, Nikolaev I, Pricelius S, Kim HS, Haaning S, Sørensen JF, Lizardo R, Functionality of a next generation biosynthetic bacterial 6-phytase in enhancing phosphorus availability to weaned piglets fed a corn-soybean meal-based diet without added inorganic phosphate. Anim Nutr. 2020 6, 24-30

displacement. This model is made under the assumption that 5% of the phosphate which is put on farmland with manure is leaching into the environment and contribute to algae bloom in lakes and rivers.

Another assessment[32] shows that the environment impacts associated with phytase application are generally very low compared with the avoided impacts obtained by MCP application (Table 2). Avoided contributions to nutrient enrichment with phytase are significantly reduced in comparison with MCP in any of the considered P-loss scenarios (0, 5 or 100% P-loss). Primary energy used to produce phytase is about 26 MJ per kg at the factory's gate, while consumption is about 400 MJ for MCP; about fifteen times more. Contributions to global warming follow the same pattern because contribution to a large extent is driven by CO2 emissions from energy conversion processes (electricity and heat production). Of note is that the relative contribution from MCP is even slightly higher due to an additional CO_2 emission during calcium oxide production from limestone. The phosphorus consumption induced by enzyme production is clearly justified by the significant savings resulting from MCP displacement. Production of one kg phytase requires 0.15 m2·year agricultural land, about the same quantity of land as required to produce 150 g bread (see Nielsen et al. 2003[33]) while no agricultural land is used to produce MCP.

✓ Environment impact is generally much lower with phytase than MCP in terms of:

- global warming (CO2)
- acidification (SO2)
- nutrition enrichment (PO4)
- phosphate rock consumption
- energy consumption
- agricultural land

Table 9: Environmental impacts induced by phytase or inorganic phosphate (MCP) application. Figures are provided per functional unit ($5 \cdot 10^6$ FYT, i.e. one kg phytase and 29 kg MCP) and refer generally to the 5% P-loss scenario, except figures in brackets which refer to the 0% and 100% scenarios, respectively).

Impact category	Phytase	MCP	MCP/phytase
Global warming, g CO2 eq.	1900	32000	17
Acidification g SO2 eq.	4,8	530	110
Nutrient enrichment, g PO4 eq.	2,2	1500 (480-21000)	700 (220-9500)
Photochemical ozone formation, g C2H4 eq.	1,5	12	8,0
Phosphate rock, g	<0,1	24000	>240000
Primary energy, MJ	26	400	15
Agricultural land, m2*year	0,15	-	-

[32] Nielsen PH, Wenzel H (2006). Environmental assessment of Ronozyme® P5000 CT phytase as an alternative to inorganic phosphate supplementation to pig feed used in intensive pig production. Int. J. Life Cycle Assess. 12, 514-520.
[33] Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R, Halberg N (2003): LCA food data base, <www.lcafood.dk>

Normalised environmental impact potentials induced by phytase or MCP application are shown in Figure 2. The figure shows that saved nutrient enrichment is by far the most significant effect of phytase application and that one kg of the enzyme product can reduce contribution to nutrient enrichment corresponding to 6% of an average Dane's yearly contribution. Application of phytase is, thus, increasingly justified by avoided contributions to global warming and acidification when phosphorus loss is approaching zero (e.g. on clayish soils with low animal density). In other words, the environmental impact caused by the enzyme is thus small compared with the impact of inorganic phosphorus.

✓ Of all environmental impacts, reduction of nutrient enrichment is biggest with phytase

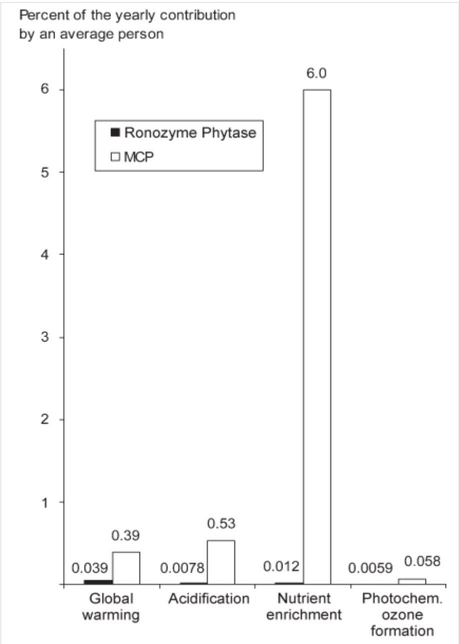


Figure 8: Normalised environmental impact potentials for phytase and MCP application (5% P-loss scenario). All data are provided per functional unit.

In this way a fermentatively produced enzyme phytase degrades phytate in the feed and makes phosphorus available to monogastric animals like poultry and swine, thereby reducing a considerable amount of phosphorus in the manure, while contributing to reduction in global warming, acidification and phosphorus and energy consumption. In conclusion phytase used in animal feeding remarkably decreases environmental cost.

10.Overall Conclusion

There are no alternatives to enzymes that are acceptable from the standpoint of the environment and of human health

"As the EU focusses on minimising chemical use and protecting "*the environment and human health from the most harmful chemicals by facilitating their phase out in non-essential uses and thereby preventing potential human and environmental exposure"*[1] the use-cases described in this document explain why enzymes are key building blocks for "zero pollution and energy- and resource-efficient technologies, materials and products". Leveraging their biological properties, **enzymes are enabling many industries in their transition towards a Circular Bioeconomy and becoming Taxonomy-compliant – which are other strategic priorities for the EU.**

Policies impacting enzymes therefore need to be assessed together, to ensure that limiting their use under one policy ambition does not hinder their essential contribution to another one.

About AMFEP

AMFEP, is a non-profit European industry association created in 1977. AMFEP currently has 30 members, representing over 90% of the European and over 80% of the world enzyme market. AMFEP serves as a hub for information exchange and dialogue between enzymes producers and formulators, industry organisations, the scientific community and policy makers and promotes co-operation on regulatory and safety aspects of enzymes.

For further information about AMFEP, please visit AMFEP's site. If you have any questions, please contact AMFEP@kellencompany.com.

For further information on the issues explored in this position paper please contact AMFEP@kellencompany.com

About EUROPABIO

EuropaBio, the European Association for Bioindustries, promotes an innovative and dynamic European biotechnology industry. EuropaBio and its members are committed to the socially responsible use of biotechnology to improve quality of life; to prevent, diagnose, treat, and cure diseases; to improve the quality and quantity of food and feedstuffs and to move towards a biobased and zero-waste economy. EuropaBio represents corporate and associate members, plus national biotechnology associations and bioregions.

Read more about our work at www.europabio.org