Rapportage projectinformatie PPS-en Landbouw, water, voedsel

Datum versie: 7 december 2020

1. Projectinformatie

1.1 Organisatie/financiering *(keuze maken)*	TKI A&F/TKI T&U/WR-PPS/overig
1.2 Projectnummer	**AF-16506**
1.3 Project titel	**Safeguarding product structure and mechanical properties while using new sustainable sources and processing steps: a multiscale and interdisciplinary approach**
1.4 Projectleider *(naam en emailadres)*	**Marcel Meinders** **Marcel.meinders@wur.nl**
1.5 Startdatum *(dd-mm-jjjj)*	**1-1-2017**
1.6 Einddatum *(dd-mm-jjjj)*	**31-12-2021**
1.7 MMIP primair *(nummer en naam van het MMIP, zie overzicht bijlage 1)*	
1.8 MMIP secundair *(deze alleen invullen als er een 2e MMIP is waar het project aan bijdraagt)*	

2. Projectomschrijving

2.1 Samenvatting *Geef een korte samenvatting van wat het project inhoudt en beoogt. Het gaat om een publiek beschikbare samenvatting (doel, bijdrage aan de missie, op te leveren resultaten in termen van kennis voor doelgroep x en de partners in het project).*
With a growing global population, food consumption will exceed from that of today. Since raw materials, energy and water are becoming scarcer, we need to adapt to more sustainable sources and production methods for our food. These methods may lie in using other food sources such as plant proteins instead of animal proteins and in using milder processing routes. The latter may include fewer purification steps, in turn implying the use of more complex mixtures as an ingredient, as opposed to first purifying these complex mixtures and then mixing them in the right proportions. In these adaptations we have to safeguard product quality, i.e. the sum of structure, mechanical (including rheological) properties, texture, taste, smell, safety, and nutritional value. All this requires a detailed knowledge on how the nature of a sustainable source and sustainable processing methods affect ingredient composition, and how the consequent compositional complexity affects final product quality. In the current project we will investigate to what extent more sustainable ingredient sources and processes can be used to manufacture products with desirable structural and mechanical properties. The strategy is twofold. One is to start with mildly purified plant extracts, investigate bulk and interfacial properties for specific product types and explore the effects of further purification of the ingredients towards less complex composition. The other is to start with mixtures of well purified ingredients form the same plant source, investigate the same bulk and interfacial properties and explore the effects of mixing of the ingredients towards more complex composition. For both strategies, plant based protein mixtures are also mixed with dairy proteins to get insights in the effect of replacement of animal by plant protein on food product structural and mechanical properties.
2.2 Doel van het project *Wat gaat het project bijdragen aan de doelen van de KIA, de missies en de MMIP's?*

In particular we aim a) to understand the conditions to produce products with desirable structural and mechanical properties from more sustainable ingredient sources, b) to quantify sustainability effects of source and processing methods for a set of sources and processes and c) to formulate main lever rules that relate the properties of sustainable produced complex ingredient mixtures for a given source to desired product properties like structure and mechanical properties on all relevant length scales. This will add to a more climate neatral food industry using more sustainable sources.

2.3 Motivatie *Licht toe waarom dit project passend en nodig is binnen het MMIP*

The project fits well and is needed in MMIP because it deals with the development of design rules, knowledge and expertise to manufacture foods in a more sustainable way, by using e.g. more sustainable plant proteins instead of animal proteins or using less pre-processing and ingredient purification, while simultaneously optimizing food properties, which includes structural and mechanical aspects. This will contribute to human health, well-being, and sustainability.

2.4 Resultaat *Zo SMART mogelijke beschrijving van de beoogde resultaten van het project. Het gaat om zowel de inhoudelijke resultaten (in relatie tot vraag 2.2) als resultaten zoals bijeenkomsten en rapporten. Geef zoveel mogelijk ook de planning per jaar.*

Key objectives

In this project we investigate the effects of more sustainable sourced materials and more sustainable process operations on food ingredient composition, and the consequences for the structural and mechanical properties of multiphase food products (emulsions/foams/filled gels). We identify the key objective as:

- To investigate to what extent more sustainable ingredient sources and processes can be used to manufacture products with desirable structural and mechanical properties.

Hereto we distinguish the following project objectives:

- Understand the conditions to produce products with desirable structural and mechanical properties from more sustainable ingredient sources.
- To quantify sustainability effects of source and processing methods for a set of sources and processes.

To formulate main lever rules that relate the properties of sustainable produced complex ingredient mixtures for a given source, to desired product properties like structure and rheological and mechanical properties on all length scales relevant to the product.

Date of delivery	Main deliverable
July 2017	List of ingredient and ingredient sources that will be used in the project. (based on maximal expected sustainability gain when using less refinement and/or replacement by animal protein as well as on commercial availability)
End of project	Insights* in to what extent mild refinement of chosen plant sources can be used to produce food products with desired structural and mechanical properties
End of project	Insights* in possible sustainability gain when using mild refinement and/or replacement of animal by plant proteins in production of food with desired structural and mechanical properties
End of project	Insights* in the relations between ingredient composition of complex mixtures of plant proteins (SP2), plant and dairy proteins (SP3, SP5a), and plant ingredients (SP1, SP4), interfacial, film, and food product structure and mechanical properties

Mid of project	Insights* in to what extent local pressures can be measured in foods (SP6)
End of project	Local dynamics measured and related to rheology for liquids that contain non-refined plant material and dairy protein mixtures (SP 6)
End of project	Generic knowledge* and a set of rules relating the key structural and mechanical properties of a specific set of products to those of the complex ingredient mixture and processing routes, including a quantification of sustainability

*** in terms of scientific papers, reports, papers, etc..**

3. Status project

3.1 Status project *(keuze maken)*	on schedule
3.2 Toelichting incl. voorziene wijzigingen t.o.v. het oorspronkelijke werkplan	The project is well on schedule. For almost all subprojects it is planned that the PhD's will defend their Thesis in 2021. SP 5a has obtained good progress in 2020, but as compared to the original planning it is behind schedule in the sense that the manuscript on the pure and mildly purified beta-glucans has not yet been finished. This is mainly the result of delay during the first two years of the project. The shift of focus towards more theoretical work, that was initiated ca. one year ago, has so far been beneficial for the motivation and productivity of the SP5 student. We therefore expect that the progress and output will stay high in the coming year.

4. Behaalde resultaten

4.1 Korte beschrijving van de inhoudelijke resultaten en hun bijdrage aan het MMIP (zoals beschreven in 2.2)

SP 1A

- Mildly purified protein extracts can stabilize interfaces and can be used in soft materials like emulsions and emulsion filled gels. The stabilization mechanism is pH dependent.
- Lipid droplets can be used as natural emulsions with tunable rheological properties. Additionally, they have an elastic dilatable monolayer which allows them to adsorb free lipids acting as emulsifiers.
- Papers published
- Results show that sustainably produced rapeseed proteins and rapeseed oleosomes are functional to make stable emulsions

SP 1B

- Mechanism of emulsification by pea proteins at pH 3 and protein purity and oil concentration on the emulsion properties was successfully investigated.
- Pea proteins were used to create elasto-plastic emulsions material

- Influence of starch on the gelling properties (heating) of pea protein stabilized emulsions
- Articles on the effect of protein purity on emulsion properties and on the emulsion properties of jammed emulsions stabilized using pea proteins
- Pea proteins at acidic pH are known to form protein particles. So, the emulsification mechanism was thought to be Pickering type. However, we successfully showed that pea proteins also exist as protein molecules at pH 3 and that these protein particles are mainly responsible for stabilizing oil droplets.
- Using this result, we further investigated the emulsion properties at acidic pH as a function of oil concentration. This investigation revealed that the unadsorbed pea protein particles create droplet-droplet contact leading to a more viscous emulsion material at pH.
- Results show that sustainably produced yellow pea proteins are functional to make stable emulsions

SP 2B

1 The genetic protein variants in yellow pea protein concentrate (PPC), legumin (PLI), vicilin (PVI) an albumin (PA) are identified and quantified using RP-UHPLC-MS (ongoing collaboration with Gijs Vreeke, PhD candidate FCH).

2 Characterisation of PPC, PLI and PVI: protein content and composition (SDS-PAGE and SEC), carbohydrate content and composition, moisture content, ash content.

3 Characterisation of PPC, PLI and PVI at pH 7.0 in diluted McIlvaine buffer (~ 20 mM Na2HPO4): protein solubility, protein composition, zeta-potential, hydrophobicity (ANSA).

4 Mixtures of legumin and vicilin (80:20, 70:30, 50:50, 30:70, 20:80) were characterised under the same conditions and using the same methods as described above.

5 Characterisation of PPC, PLI and PVI at pH 4.8 in McIlvaine as function of NaCl: protein solubility.

a. At pH 4.8 PVI reached a maximum solubility of 90 % at 300 mM NaCl, whereas PLI only reached a maximum solubility of 66 % at 750 mM NaCl (12.5 g L-1 protein).

6 The interfacial tension and elastic modulus (air-water and oil-water interface) of PPC, PLI, PVI and L:V blends (70:30, 50:50, 30:70) were measured at 0.05 g/L in diluted McIlvaine buffer at pH 7.0.

a. The legumin:vicilin ratio did not have an effect on the surface pressure/time at the oil-water interface, since there were no significant differences in the surface pressure/time of PPC, PLI, PVI and PLI:PVI blends.

7 Emulsion properties (individual droplet size and flocculation) were analysed for 10 % (v/v) oil-in-water emulsions made with 0.5, 1.0, 2.5, 5.0, 10.0 g/L PPC, PLI, PVI and PLI:PVI blend (30:70).The samples were prepared and analysed in diluted McIlvaine buffer at pH 7.0. The legumin:vicilin ratio did not have an effect on the individual emulsion droplet size, since there were no significant differences in the emulsifying properties (d3,2,single vs Cprot) of PPC, PLI, PVI and the PLI:PVI blend. Emulsion droplet flocculation was observed for all pea protein emulsions at low protein concentration. This flocculation has not been observed for common animal-derived protein stabilized emulsions, e.g. using WPI. At high protein concentrations, no flocculation of the pea protein emulsions was observed.

8 A good prediction of the d3,2,single vs Cprot for the pea protein and whey protein isolate emulsions was made using the extended surface coverage model. The relative diffusion coefficient was introduced in the model to account for the differences in radii of the proteins.

9 The study of the effect of NaCl on the molecular, interfacial and emulsion properties of PPC, PLI and PVI in the iso-electric point (pH 4.8) is ongoing.

10 Finalized MSc thesis, Madelon Derwig: “The effect of pre-processing of pea legumin and vicilin on the molecular, interfacial and foaming properties”

a. PVI and PLI were heated at 100 °C for 30 minutes (pH 7.0, ~ 20 mM Na2HPO4 and pH 7.0, ~ 200 mM Na2HPO4). Soluble aggregates were formed in all samples and in addition insoluble aggregates were formed in PVI at high ionic strength. The foam ability and stability of PVI significantly increased after heating, whereas there was no difference in the foam properties of PLI before and after heating. But, the (change in) foam properties could not directly be related to the molecular properties (size, charge and hydrophobicity) of the proteins. The foam properties of both yellow pea and rapeseed proteins will be studied in more detail.

- Results adds to a better understanding of the behaviour of plant proteins and therefore to replace animal proteins without comprimising on product quality and therefore allowing for more sustainable food production

SP 3

- Conformation of plant protein blends studied at interfaces during stay at INRAE, Nantes, made possible through the Aalt Dijkhuizen travel grant, and the hospitality of INRAE
- Surface rheology, using microfluidic techniques was investigated. In this way she completed the research on the smallest and shortest time scale that we considered, that of the nanoscale, and found very interesting results. Especially that the conformation of proteins was influenced by their isolation method, and that early film formation already happened within a second were new insights that contribute to the fundamental knowledge needed to achieve more sustainable food emulsions.
- Three papers published, 2 in preparation, and submitted, PhD thesis completed in draft shape and submitted to the committee. The graduation date is April 1st, 2021.
- Results adds to a better understanding of the behaviour of blends of plant and dairy proteins and therefore to replace animal proteins without comprimising on product quality and therefore allowing for more sustainable food production

SP4

- Influence of defatting on interfacial and foam properties of mildly purified rapeseed protein concentrate (RPC) studied. The lipids in the RPC did not influence the foaming properties, as the lipids are trapped in the form of oleosomes. This work has been published in August 2020.
- The influence of rapeseed phenol sinapic acid on the whey protein interfacial and foam properties studied. The sinapic acid negatively influences the interfacial layer strength and foaming properties of whey proteins. This work has been published in November 2020.
- A follow-up study started based on the results of the first mentioned work (defatting of RPC), where the interfacial properties of oleosomes were further studied. We discovered that oleosomes can rupture at the air-water interface and form oil- and phospholipid-dense regions. Oleosomes were also mixed with whey proteins, and we discovered a mixed interface, where oleosomes dominated the rheological properties at small deformation amplitude, but the lipids were pushed out at large deformation amplitudes. Manuscript in preparation.
- The oleosome-whey protein system was a model system to study the interfacial properties. In the next step, we mixed RPC with oleosomes to study the influence of oleosomes on RPC foaming properties. We discovered a concentration-dependence, where oleosomes substantially decreased foam formation and stability at low RPC concentrations (<0.2% w/w). At higher protein concentrations, the detrimental effect of oleosomes decreased.
- Results adds to a better understanding of the behaviour of plant proteins and the role of minor components in the mixtures and therefore to replace animal proteins without comprimising on product quality and therefore allowing for more sustainable food production

SP5A

- Different pea fractions were obtained and studied on their viscoelastic behaviour upon and after heating (published). And A study on the effect of fractionation processes on the ability of pea protein to form coacervates was initiated.

Conclusions: limited fractionation of yellow pea protein yields stronger gels than those extensively fractionated. Different factors cause a reduced gelling capacity have been identified: isoelectric precipitation, amount of sugar upon lyophilization, differences in salt content and the pre-aggregated state of pea protein.

- Multiple pea protein fractionation routes were explored and functionalities (i.e. solubility, viscosity, gelling) of the resulting fractions were compared to whey protein isolate (submitted) and the interactions between pea protein fractions and whey protein isolate upon heating was also studied (draft manuscript written)

Conclusions: 1) fractionation could be optimized so that pea protein isolate behaved similar to whey protein isolate with regard to its viscosity, solubility and gel strength. 2) Whey protein isolate was also substituted by the pea protein isolates. It was concluded that a diafiltrated pea protein isolate could fully replace whey protein isolate up to protein concentrations of 15 wt. %. For mixtures of whey protein isolate with the other PPI's, it turned out that half of the whey protein isolate could be replaced by any of the PPI's without compromising on gel strength. 3) globulin-rich fractions in admixture with whey protein, electrostatic interactions and hydrophobic interactions are dominant upon heat-induced gelation. For fractions containing albumins combined with whey protein isolate, it is suggested that disulphide bonding and hydrogen bonding play a more important role upon heat-induced gelation.

- The emulsifying and foam properties of globulin- and albumin-rich pea fractions were studied (collaboration with SP4, draft manuscript written) and a study on pea protein fractions and their ability to form emulsion filled gels was initiated.(collaboration with SP1B).

Conclusions: 1) In contrast to globulins, albumins showed excellent foam properties, similar to whey protein isolate. 2) In contrast to albumins, globulins showed good emulsifying properties. 3) Different fractionation routes influence the ability of pea protein to form emulsion filled gels, and also affects the influence of oil on the gel strength.

- Results adds to a better understanding of the gelling behaviour of yellow pea proteins with or without mixed with dairy proteins and therefore to replace animal proteins without comprimising on product quality and therefore allowing for more sustainable food production

SP5B

- Experimental characterization of the influence of oat and barley beta-glucans on the demixing of whey protein stabilized O/W emulsion gels, for pure and mildly purified beta-glucans.finished. Literature describing the different mechanisms of demixing relevant for this subject studied. Manuscript in preparation.
- Review/meta-analysis of published data: effects of non-adsorbing polysaccharides on demixing of gelled emulsions started. Relevant papers selected and ideas developed ideas types of quantitative analysis to apply to the data.
- Population balance model developed in cooperation with SP7A that predicts predicts flocculation and creaming and thus gel formation of emulsions.
- Results adds to a better understanding of the emulsion stability of complex impure protein mixtures and therefore to increase functionality of sustainable, less processed, ingredients.

SP6

- Molecular Rotors: Polymers: Focus was set on finalizing the project on probing polyethylene glycol polymer solutions as model systems for more complex foods. We found that the fluorescence of molecular rotors embedded in polymer solutions scales with monomer concentration, instead of macroscopic viscosity. Thus, the use of molecular rotors in complex fluids allows to not only give insight into the viscosities of these solutions, but also to predict molecular length scales within these systems. Additionally, we succeeded in affirming our claims by adding a theoretical foundation. The work will be submitted shortly.
- Emulsion destabilization by drop evaporation. This work introduced in the last period has been published: https://www.nature.com/articles/s41598-020-71964-1
- Molecular Rotors: Emulsions. In addition to studying the fluorescence of molecular rotors in polymer solutions we also use them to study local viscosities in oil-in-water emulsion systems. Using

fluorescence lifetime microscopy, we observe that the dye lifetime (and thus local viscosity) significantly varies across the bulk of the oil droplets and their interfaces. Surprisingly, by using an oil-soluble molecular rotor we also observe a dependence of the measured fluorescence on the size of the oil-droplets. We will focus on finalizing this project within this period.

- Results adds to a better understanding of the emulsion stability of complex impure protein mixtures and therefore to increase functionality of sustainable, less processed, ingredients.

SP7A

- Data collection for model validation running
- Design of experiments SP1B implemented and additional experiments performed
- Mechanistic model of emulsification process using high pressure homogenizer implemented, using population balance equations, including droplet breakup due to shear and droplet coalescence. Key parameters for droplet size distribution calculation are HPH pressure and number of passes, oil volume fraction and dynamical oil/water interfacial tension and coverage, which depend on the interfacial properties of the emulsifier.
- Mechanistic model to describe droplet aggregation and creaming implemented using population balance equations.
- Mechanistic model for protein adsoprtion and interfacial properties based on thermodynamics free energy developed
- Started with development of mechanistic models for 2D and 3D rheology of soft particles, as model system for sus[pensions such as protein (aggregate) mixtures and emulsions.
- Brownian dynamics model implemented using LAMMPS to study aggregation and gellation and rheology of suspensions and emuslions (collaboration with TUE)
- Brownian dynamics model implemented using LAMMPS to study adsorption an interfacial rheology of proteins. (collaboration with TUE)
- Results adds to a better understanding of the relation between ingredients, process and product (emulsion, high protein drinks, foams and gels) and the effect of using less purification and more plant instead of animal proteins and therefore allows for the pruduction of more sustainable foods while mainaining or improving product quality.

SP7B

- Database with sustainablilty information on processses and crops regularly updated
- Case scenarios for quanitifying sustainability in production of commercial emulsion and high protein drink included.
- Flow schemes for all major crops relevant to the chosen products identified and relevant parameters stored in database
- Valorisation of by-products was included in sustainability model, including now economic, exergy allocation and system expansion
- Proof of principle for reverse engineering for sustainable processing ‘rules of thumb’ showcased (requirements (composition of the product) of partners was included, input on functionality and formulation needs to come from project SP’s)
- Manuscript drafted on extended model: effects of by-product valorisation
- Validation of model (uncertainty analysis) performed to improve robustness of the sustainability model
- Scenarios for ingredient processing from SP1A, 1B and 5A (rapeseed and yellow pea) as well as 7A (process) completed. (still frequent contact between 7A and 7B to optimize database and sustainability model)
- Results quantifies sustainaiblity parameters for food production in combination with product quality and allows for optimization of product quality and sustainabillity.

4.2 Deliverables (bijeenkomsten en andere output, die niet benoemd wordt in 4.3 en 4.4)
4.3 Communicatie (lijsten)
4.3.1 Wetenschappelijke artikelen en hun doi (*Digital Object Identifiers)*
• Ntone, E., Bitter, J. H., & Nikiforidis, C. V. (2020). Not sequentially but simultaneously: Facile extraction of proteins and oleosomes from oilseeds. Food Hydrocolloids, 102, 105598. • Ntone, E., van Wesel, T., Sagis, L., Meinders, M., Bitter, J., & Nikiforidis, C. (2020). Adsorption of rapeseed proteins at oil/water interfaces. Janus-like napins dominate the interface. Journal Of Colloid And Interface Science, 583, 459-469. • Ntone, E., Rosenbaum, B., Sridharan, S., Willems, S., Moultos, O., Sagis, L., Meinders, M., Bitter, J., & Nikiforidis, C. (2020). The supremacy of lipid droplet monolayer (In preparation)Sridharan, Simha, et al. "Pea flour as stabilizer of oil-in-water emulsions: Protein purification unnecessary." Food Hydrocolloids 101 (2020): 105533 • Sridharan, Simha, et al. "On the emulsifying properties of self-assembled pea protein particles." Langmuir 36.41 (2020): 12221-12229. • Hinderink et al., Sequential adsorption and interfacial displacement in emulsions stabilized with plant-dairy protein blends EBA Hinderink, L Sagis, K Schroën, CC Berton-Carabin Journal of Colloid and Interface Science 583, 704-713 • Hinderink et al., Microfluidic investigation of the coalescence susceptibility of pea protein-stabilised emulsions: effect of protein oxidation level EBA Hinderink, W Kaade, L Sagis, K Schroën, CC Berton-Carabin Food Hydrocolloids 102, 105610 • Hinderink et al., Behavior of plant-dairy protein blends at air-water and oil-water interfaces, E Hinderink, L Sagis, K Schroën, CC Berton-Carabin, Colloids and Surfaces B: Biointerfaces, 111015 • Yang, J., Faber, I., Berton-Carabin, C. C., Nikiforidis, C. V., van der Linden, E., & Sagis, L. M. C. (2020). Foams and air-water interfaces stabilised by mildly purified rapeseed proteins after defatting. Food Hydrocolloids, 112(August 2020), 106270. https://doi.org/10.1016/j.foodhyd.2020.106270 • Yang, J., Lamochi Roozalipour, S. P., Berton-Carabin, C. C., Nikiforidis, C. V., van der Linden, E., & Sagis, L. M. C. (2021). Air-water interfacial and foaming properties of whey protein - sinapic acid mixtures. Food Hydrocolloids, 112, 106467. https://doi.org/10.1016/j.foodhyd.2020.106467 • Kornet et al: Yellow pea aqueous fractionation increases the specific volume fractions and viscosity of its dispersions, https://doi.org/10.1016/j.foodhyd.2019.105332 • Kornet et al: Less is more: Limited fractionation yields stronger gels for pea protein, https://doi.org/10.1016/j.foodhyd.2020.106285 • Kornet et al. Substitution of pea protein by whey protein is facilitated by specific fractionation routes, submitted to Food Hydrocolloids • Bitterman et al. Deposits from evaporating emulsion drops https://www.nature.com/articles/s41598-020-71964-1
4.3.2 Rapporten/artikelen in vakbladen
4.3.3 Overige communicatie-uitingen (inleidingen/posters/radio-tv/social media/workshops/beurzen)
Presentations/posters • Sridharan et al. Oral presentation at international hydrocolloid conference 2020, Melbourne, Australia. Emulsifying mechanism of pea proteins at pH 3: Is it Pickering? • Kornet et al. 15th International Hydrocolloids Conference (Melbourne) – 2020 • Meijers et al.: Oral presentation NIZO Plant protein functionality conference 2020, online, “Towards predicting the emulsion properties plant protein mixtures”. • Meijers et al.: Invited oral presentation during Food Science Symposium 2020, Wageningen, The Netherlands, “Towards predicting the emulsion properties plant protein mixtures”.

- Meijers et al.: Oral presentation during Bubble and Drop Conference 2019, Sofia, Bulgaria, “Predictive estimation of emulsion properties of pea legumin and vicilin blends” Presenting author M.G.J. Meijers, MSc.
- Meijers et al.: Oral presentation during Bubble and Drop Conference 2019, Sofia, Bulgaria, “Protein stabilised emulsions and foam” Presenting author Dr.ir. P.A. Wierenga.
- Meijers et al.: Poster for Food Colloids 2018, Leeds, “Predictive estimation of emulsion and foam properties of plant protein mixtures”
- Meijers et al.: Oral and poster presentations during PhD trip in Switzerland and Italy.
- Hinderink et al. Accepted abstract for the 4th Food Structure and Functionality symposium (Cork, Ireland) and Food Colloids (Lund, Sweden) ‘Microfluidic investigation of the coalescence susceptibility of emulsions stabilised by whey-pea protein blends’. Was canceled due to Covid19

MSc and BSc thesis

- Maria Georgopoulou, MSc. The effect of purification processes on yellow pea protein emulsifying and foam properties
- Carol Shek, MSc. Influence of fractionation on the thickening- and gelling behaviour of individual and mixed pea / whey protein isolates upon thermal treatment
- Dirk Wijnen, BSc. Physicochemical properties of pea flour stabilized emulsion filled gels
- Simone Penris, MSc. Interactions between pea and whey protein upon heating

Workshops

- TiFN Mid-term review, 7-5-2020
- TiFN Results to success, 26-6-2020

TiFN Partner visits

- Bel, 26-11-2020, on-line
- Pepsico, 28-09-2020, on-line
- Bel, 17-09-2020, on-line

4.4 Overige resultaten: technieken, apparaten, methodes

4.5 Projectwebsite: geef het adres van de projectwebsite (indien beschikbaar)

https://www.tifn.nl/sustainable-ingredients/