3rd partial report for the GUDP project Græs-Prof, Working Package 3

EVALUATION OF DIFFERENT MACERATION TECHNOLOGIES OF THE FRESH BIOMASS

Test of maceration methods to increase the extraction of valuable components in 2022

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Experiments were carried out in 2022 on the demonstration platform for research and development of Green Biorefining at AU Viborg, research unit Foulum.

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Resume

Formålet med Græs-prof-projektets arbejdspakke 3 var at udvikle, demonstrere og sammenligne egnede teknikker til håndtering og nedbrydning af den grønne biomasse inden saftpresningen på Aarhus Universitets demonstrationsplatform for grøn bioraffinering i AU Viborg, Foulum.

På demonstrationsplatformen blev forskellige macerationsmetoder (neddelingsmetoder) testet for at sammenligne deres effektivitet i forhold til neddelingen af græsset. Metodernes ydeevne blev målt i forhold til energiforbrug, kontinuitet, kapacitetsudnyttelse og især juice- og proteinudbytte i juicen efter skruepresning. Seks forskellige grønne biomasser med forskelligt vandindhold, proteinindhold, plantestruktur og blad/stængel-forhold indgik i testene.

Når græsser og bælgfrugter høstes, skal de nedbrydes effektivt og gerne umiddelbart, inden de går i skruepressen for at sikre et højt saft- og proteinudbytte gennem hele processen. Højt udbytte er afgørende for, at grøn bioraffinering bliver økonomisk og miljømæssigt bæredygtig - jo mere protein, der kan presses ud af biomasserne, jo bedre.

I 2022 blev forskellige macerationsmetoder testet før vådfraktionering af grøn biomasse og ekstraktion af proteinkoncentrat. Heraf blev to standardiserede og to højintense macerationsmetoder undersøgt på seks forskellige typer grøntafgrøder. Undersøgelsen havde til formål at øge udvindingen af proteinkoncentrat som erstatning for sojaskrå i foder, til enmavede dyr, som f.eks. grise, og samtidig udvinde simple sukre og lipider til yderligere værdiskabelse. Brugen af højintense macerationsmetoder før biomassefraktioneringen fremmede en mere robust mekanisk nedbrydning af plantebiomassen, hvilket førte til højere ekstraktion af de opløselige forbindelser. Den højeste ekstraktionseffektivitet i råproteinet var i rødkløver (29%) og rajsvingel (28%). Det højere energibehov, der følger med mere avancerede tekniske processer, bliver kompenseret af den betydelige stigning i proteinudbyttet.

Description of the maceration tests in 2022

The maceration methods tested in the 2022 season consisted of several process steps and aimed to compare two much more thorough maceration methods to two standard methods previously tested at the demonstration platform in Foulum. The full process can be seen in Figure 1. Six different biomasses were used as feedstock: two types of grass, festulolium and perennial ryegrass; three types of legumes, lucerne, white clover, and red clover; and a grass-clover mixture. In the biorefinery, the harvested biomass is submitted to a maceration step before they are sent to the screw press, where a solid fiber press cake is separated from the green juice. This juice, rich in proteins, is heated and the protein concentrate is separated from the residual juice, also known as brown juice. The description of the experiments at the demonstration platform can be seen in the following video: [Great potential in Danish Green Biorefinery – from grass to products - YouTube]

To increase the protein yield, different maceration methods were tested. Those methods are highlighted in the blue box. The standard maceration methods refer to the in-field cutter, when the biomass is directly cut in the field when it is harvested, and the stationary cutter, when the harvested biomass is cut in the demonstration plant using a homebuilt cutter. The extra cutting step refers to the severe maceration methods that the biomass went through before the screw press. The dashed lines refer to the severe maceration methods.

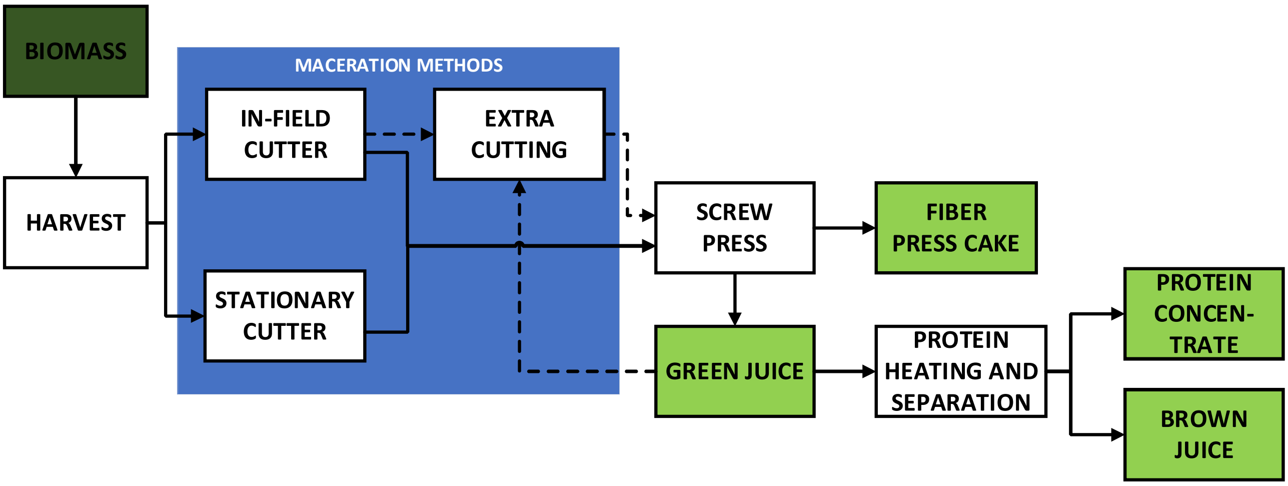

Figure 1: Process flow diagram of the different setups used for the maceration tests carried out in 2022 at the green biorefining demonstration platform.

The different severe maceration methods are shown in Figure 2. These processes steps include a custom-made mixing vessel for mixing freshly harvested green biomass in liquid (either water or recycled green juice), a pump that pumps the mixed liquid stream through the system, a shredder (Vogelsang RotaCut RC 3000) that produces a homogeneous suspension, and subsequently two different maceration steps: a wet mill (Vogelsang DisRuptor DR7000) or a deflaker (Grubbens Labyrinta Deflaker 360B) in which the biomass is further crushed through the process equipment. After the use of the disruptor or deflaker, the suspension goes to a dewatering separator (Cir-Tech SCUD 6000) to separate most of the liquid phase from the biomass suspension. Similarly to the standard methods, the process continues in the screw press, where the green juice is squeezed out of the biomass. The severe maceration tests were based on biomasses that were cut during harvest in the field.

Table 1 shows the different biomasses tested and the dry matter and crude protein content present in the fresh biomasses. It also displays which maceration method was tested for each biomass. In the experiments, it was assumed that the biological activity of the biomasses was the same, regardless of the cutting type, since the time between harvesting in the field and processing was kept as constant as possible, and all biomass was processed after a maximum of 2 hours after harvest. However, it is important to highlight that even minor time differences between the tests can also affect the results, especially if there have been differences in temperature, water content, and biological activity on the days when the experiments were made.

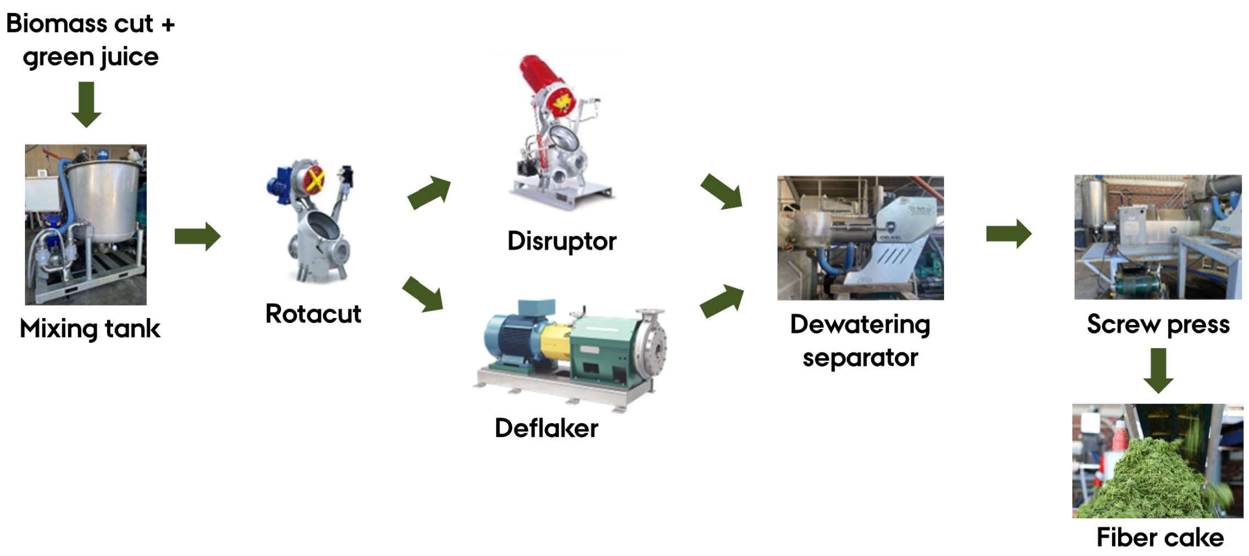

Figure 2: Severe maceration setups tested at the demonstration platform.

Table 1: Dry matter content, crude protein content, and maceration methods of the different biomasses. Festulolium, ryegrass and grass-clover were processed between May and August. Lucerne, red clover, and white clover were processed in late September.

Green Biomass	DM content [%]	CP content [% DM]	Standard maceration		Severe maceration	
			In-field cutter	Stationary cutter	In-field + Disruptor	In-field + Deflaker
Festulolium	16.6	20.4	x	x	x	x
Ryegrass	17.5	19.9	x	x	x	x
Grass-Clover	21.0	15.5	x	x	x	x
Lucerne	18.0	24.8		x		x
Red clover	18.7	19.0		x		x
White clover	19.2	19.2		x		x

The experiments were carried out between May and October 2022. For all biomasses, each maceration study was carried out as close to each other as possible, typically on the following days. The heat precipitation of the green juice was kept constant at 85 °C. The experiments analyzed samples in all process streams. The main results focus on the final products (fiber press cake, brown juice, and protein concentrate) in terms of dry matter content, crude protein content, and ash content.

The energy consumption of the different setups was measured and evaluated. It is important to remember that the energy consumed on the demonstration platform might not be the same as when it is used commercially.

This occurs because the energy setup is not optimal, the equipment is not used to the fullest, and the testing goes on for a long time. In any case, it is good enough to directly compare the different maceration scenarios.

Figure 3 gives an example of a mass balance for the fiber pulp, green juice, and protein concentrate, calculated in wet weight (FM = fresh matter), dry matter (DM), and crude protein (CP). This example can be used to understand the mass balance results in the report. An example is a typical mass balance achieved on the demonstration platform in Foulum in the start-up year 2019 without significant optimization of the process. It can be seen in the figure that only 8% of the input dry matter and 21% of the crude protein end up in the protein concentrate. This is approximately half of what is needed to make the business model commercially feasible, and it emphasizes that there is a need to improve the yield of protein extraction, for example with better maceration.

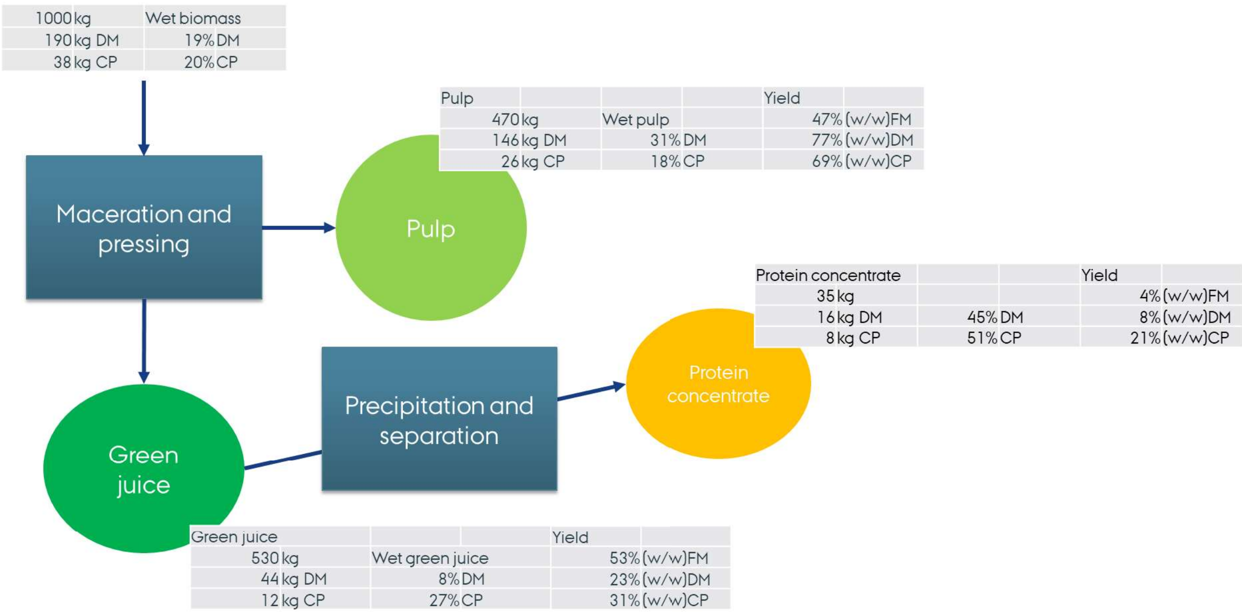

Figure 3: Example of mass balance for fiber pulp, green juice, and protein concentrate, calculated in wet weight (FM), dry matter (DM), and crude protein (CP) contents. Brown juice is not included in the figure. Since the example assumes a closed mass balance without loss, the remaining amounts of wet weight, dry matter, and crude protein can be attributed to brown juice. Thus, 49% (w/w) FM, 15% (w/w) DM, and 10% (w/w) CP will end up in the brown juice.

Results and Discussion for the maceration tests in 2022

Quality of fiber cake and protein concentrate

Table 2 presents the measurements for how much dry matter, crude protein, and ash content are in the fiber and protein concentrate fractions of the six different biomasses when processing the biomasses at the demonstration plant in the 2022 season. When the biomass was cut in the field instead of in the stationary cutter, the fiber had a higher dry matter. On the other hand, using severe maceration (disruptor or deflaker) resulted in less dry matter in the fiber compared to using just one maceration stage (in-field and stationary cutters) because more dry matter was extracted to the green juice. The protein concentrate fraction, especially from legumes (white clover, red clover, and lucerne), had more dry matter when the deflaker macerator was used.

Table 2: Dry matter, crude protein, and ash content of the fiber press cake and protein concentrate fractions after different maceration methods.

Green Biomass Maceration	DM content [%FM]		CP content [%DM]		Ash content [%DM]	
	Fiber press cake	Protein concentrate	Fiber press cake	Protein concentrate	Fiber press cake	Protein concentrate
Festulolium						
In-field	36.8	46.6	17.3	56.4	5.5	7.3
Stationary	31.2	47.2	17.1	57.6	5.5	5.5
Disruptor	32.2	48.9	12.9	53.8	4.4	5.3
Deflaker	28.3	51.6	14.7	55.6	6.8	7.2
Ryegrass						
In-field	37.1	46.9	13.1	60.6	3.7	5.5
Stationary	25.5	47.1	17.3	55.5	5.2	5.6
Disruptor	29.5	44.4	15.6	45.3	5.1	5.2
Deflaker	27.9	50.6	18.5	49.8	7.5	9.4
Red clover						
Stationary	32.2	42.0	17.2	45.6	9.0	11.2
Deflaker	31.6	56.9	15.7	37.2	N.A.	N.A.
White clover						
Stationary	27.9	44.4	19.1	43.9	7.8	11.7
Deflaker	26.6	53.0	18.4	39.5	11.5	17.7
Lucerne						
Stationary	30.4	50.3	19.9	55.8	8.0	5.1
Deflaker	33.5	58.1	16.7	48.8	14.7	14.5
Grass-Clover						
In-field	31.2	42.5	13.4	45.6	6.7	9.4
Stationary	30.7	44.4	14.6	46.9	6.3	7.3
Disruptor	32.0	32.0	15.4	38.5	5.3	11.1
Deflaker	32.6	43.3	13.7	41.5	7.1	7.8

In terms of crude protein, when severe maceration methods were used, the amount of protein in the fiber part tended to be lower than in processes with in-field or standard cutters. Severe maceration pulls out not only protein but also other solids from the biomass. Although the protein content that ended up in the protein concentrate increased, having more of the other substances in this fraction decreased the protein level. Among the different biomasses, red and white clovers had the least protein in the protein concentrate, followed by the grass-clover mixture. The highest protein content in the protein concentrate was found in the festulolium. Overall, the concentration of crude protein in the fiber decreased when severe maceration was applied.

The variability of ash content is greater due to external elements that may affect it, including weather conditions and frequency of harvesting. However, processing legumes resulted in higher ash levels in both the fiber and protein concentrate fractions, for the standard and severe macerations. In cases of severe maceration procedures, particularly when utilizing the deflaker macerator, higher ash content was extracted.

Distribution of dry matter in fiber cake, brown juice, and protein concentrate

Figure 4 shows the distribution of the dry matter between the three product fractions that come out of the biorefining process: fiber pulp, brown juice, and protein concentrate.

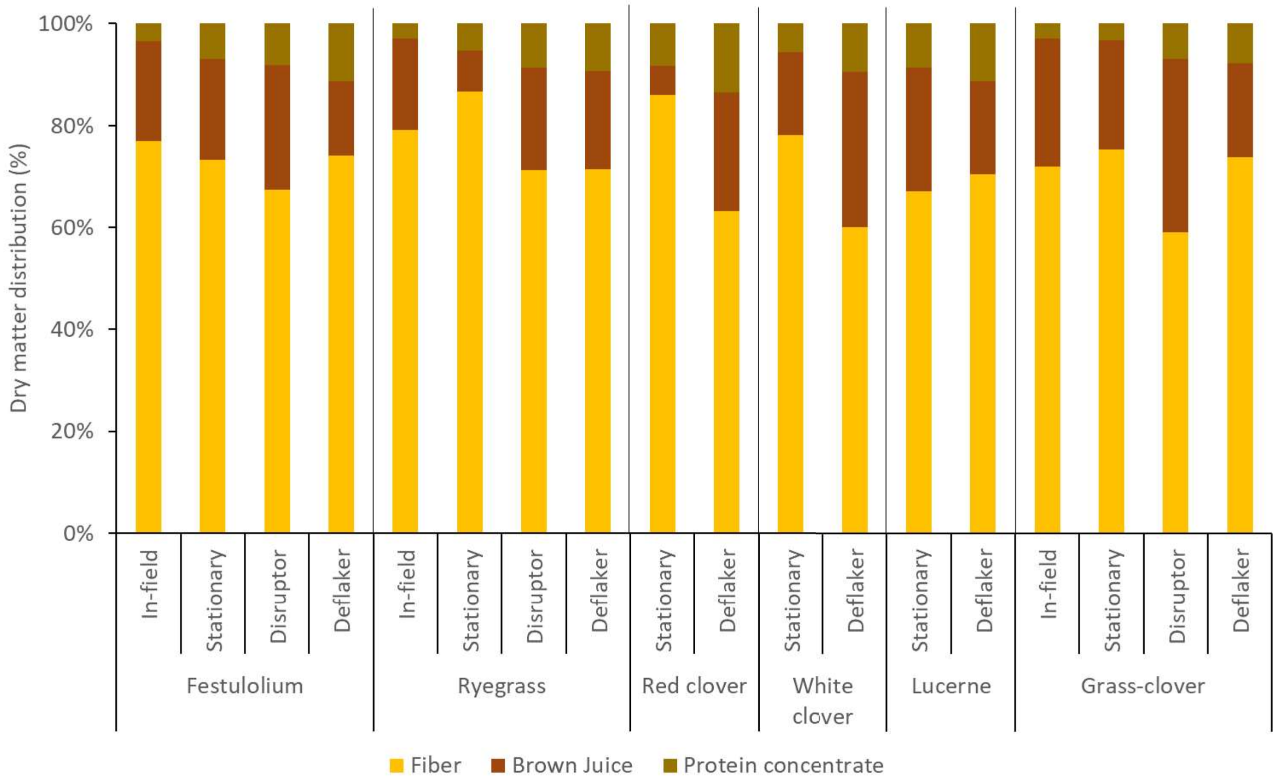

Figure 4: Dry matter distribution in the fiber pulp, brown juice, and protein concentrate under different maceration processes.

Distribution of crude protein in fiber cake, brown juice, and protein concentrate

Figure 5 shows the distribution of the crude protein to the same product fractions. In terms of dry matter, the protein concentrate increased by up to 50% if the stationary cutter was used instead of the in-field cutter. Severe macerations resulted in around 25% less dry matter that ended up in the fiber than when using the stationary cutter, showing the high performance of the disruptor and deflaker. In addition, the dry matter in the protein concentrate increased by 40% for the grasses, 30% for the legumes, and 56% for the grass-clover. When the deflaker was used, more than 10% of the dry matter from festulolium, lucerne, red clover, and white clover was found in the protein concentrate. However, severe maceration increased the dry matter content found in the brown juice. This is probably due to the setup implemented on the demonstration platform. The use of green juice to mix with the biomass in the mixing tank results in a higher resting period for the juice. The long period while the juice is not processed can result in protein degradation and decrease the process efficiency.

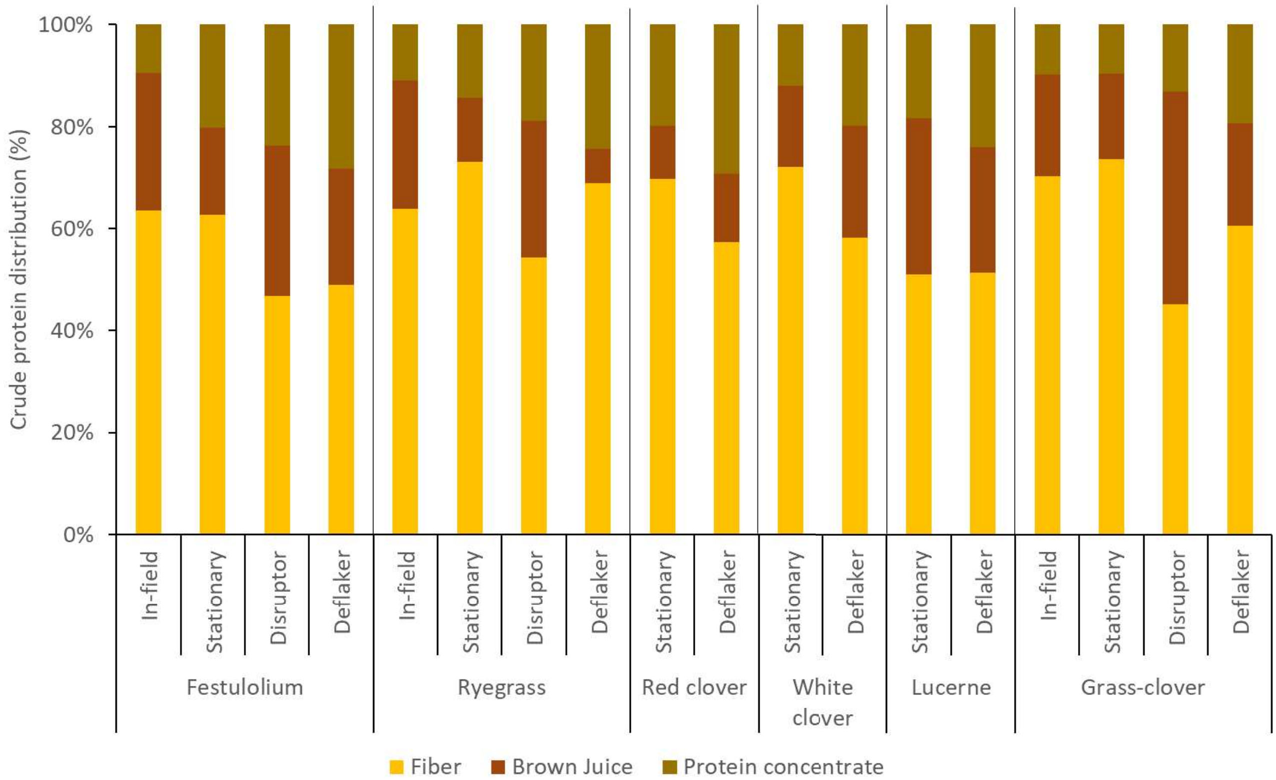

Figure 5: Crude protein distribution in the fiber pulp, brown juice, and protein concentrate under different maceration processes.

When comparing how biomasses are broken down in the field versus when stationary, the amount of crude protein obtained from the protein concentrate increased by 53% and 24%, respectively, when festulolium and ryegrass were processed. The increase of crude protein obtained from the protein concentrate was even more significant with severe macerations: the part of crude protein ending in the protein concentrate went up by 66% for festulolium, 55% for ryegrass, and 50% for grass-clover. A smaller increase was seen in the protein concentrate from legumes, where there was an average of 32% more crude protein under severe maceration. Among the methods studied, the deflaker performed better than the disruptor. On average, the deflaker macerator yielded about 23% higher portion of crude protein in the protein concentrate compared to the disruptor for grasses and grass-clover. The deflaker macerator got the largest quantity of crude protein in the protein concentrate from red clover, achieving 29% of the available crude protein. In festulolium, the deflaker resulted in 28% extraction, while both lucerne and ryegrass had 24% crude protein extraction. For the disruptor, the best scenario was 24% crude protein from festulolium in the protein concentrate.

The grass-clover mixture used in 2022 (ForageMax 55) was composed of 10 % white clover, 65 % ryegrass, and 25 % red fescue. The overall low grass-clover performance was because of the high content of red fescue in the biomass mixture, resulting in lower protein concentration in the fresh biomass. In 2021, a different grass-clover mixture (ForageMax 45), which included 7% white clover, 11% red clover, 37% ryegrass, and 45% festulolium, achieved up to 44% crude protein extraction in the protein concentrate. This can be observed in Figure 6.

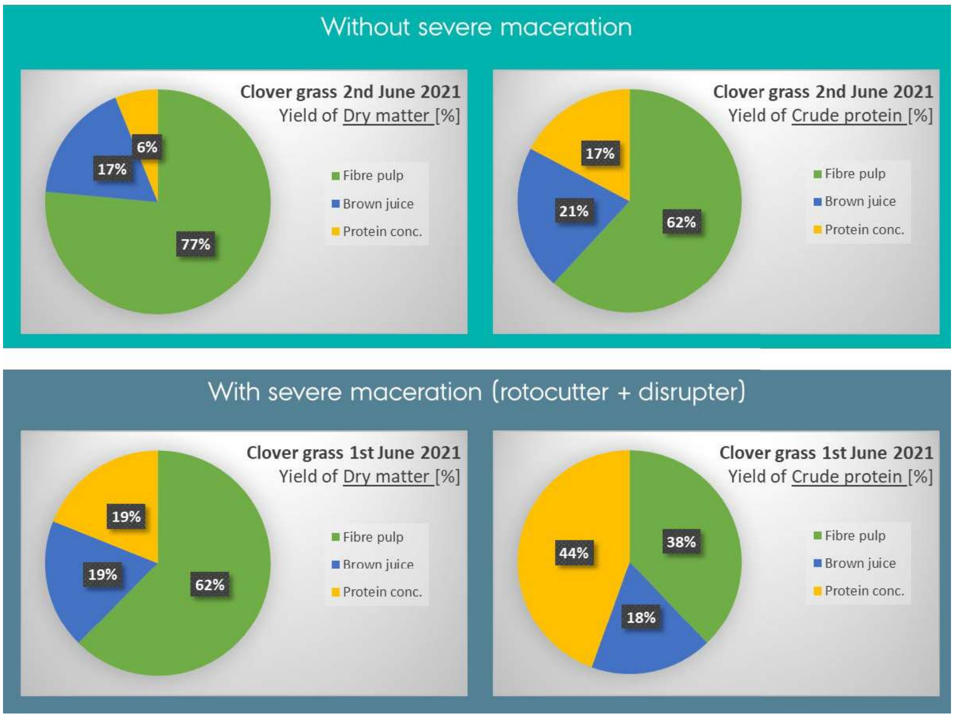

Figure 6: Dry matter and crude protein percentage (mass out/mass in) for the first maceration test in June 2021 processing grass-clover.

Energy consumption

It was observed that most of the energy is consumed in two stages of the process: during the maceration of the biomass and when the protein concentrate is dried. Around 40-50% of the total energy is consumed in the maceration and screw press, while 25-40% of the total energy is used to dry the protein concentrate.

Overall, the processes using severe maceration consumed at least 30% more energy in the maceration. This was observed because when the severe maceration methods were used, more equipment was necessary in the process setup. This includes a mixing tank, a rotacut, a disruptor or a deflaker, and a dewatering separator. In terms of total energy, the consumption increased by 60% when the grasses and grass-clover mix were processed and increased by 25% when legumes were processed. Grasses contain a higher proportion of stems in their structure than legumes. More energy is required to break down stems than leaves. Because of that, processes with festulolium, ryegrass, and grass-clover mixture consume more energy than processes with white clover, red clover, and lucerne.

The effect of the addition of extra equipment in the severe maceration steps is shown in Figure 7. This figure displays the energy necessary in the process divided by the amount of protein concentrate produced when 1 tonne of biomass is processed in the demonstration platform. It was observed that, even though more energy is necessary in the processes with severe maceration, more protein concentrate is obtained. The higher amount of protein concentrate compensates for the higher energy consumption and justifies the use of severe maceration processes.

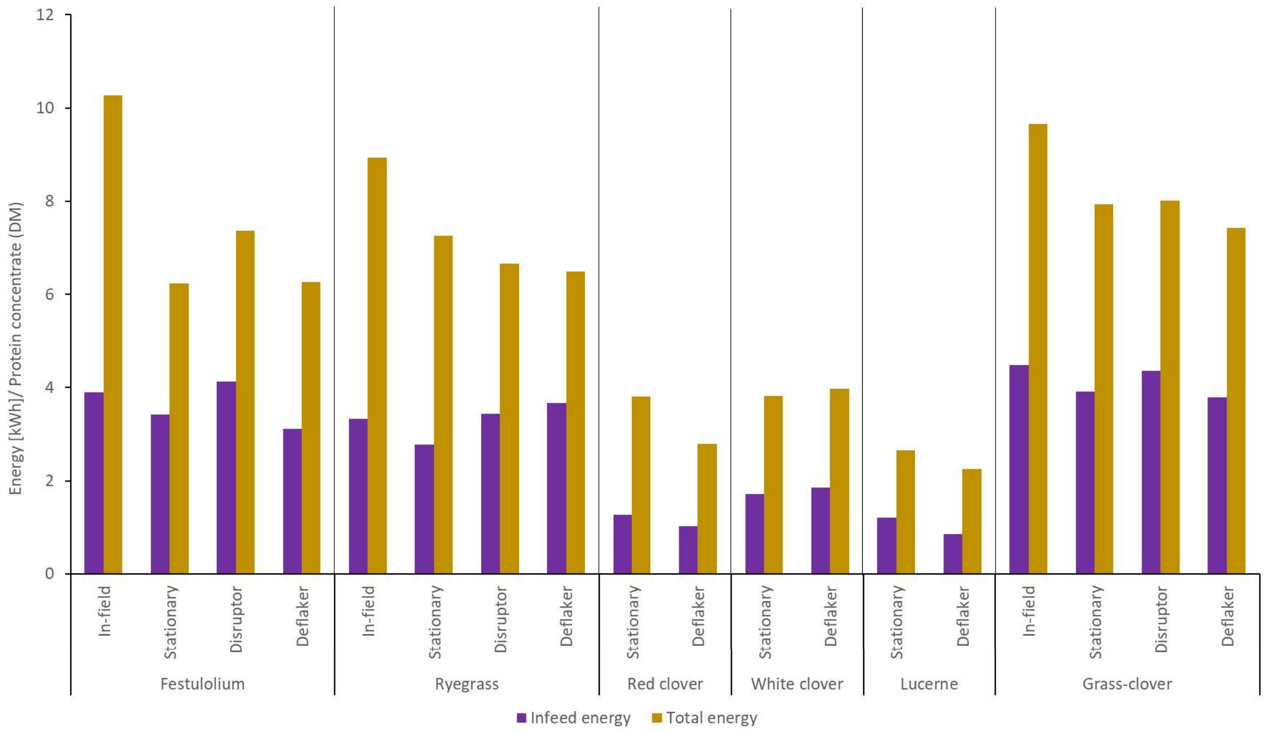

Figure 7: Energy consumed per protein concentrate produced when processing 1 tonne of fresh biomass. The infeed energy refers to the energy consumed in the maceration and screw press. The total energy includes the energies consumed for heating and separation, drying of the protein concentrate, and storage.

Conclusion

The use of severe maceration processes to help the breakdown of the grasses and legumes shows great potential to increase the yield of the protein concentrate. Additional equipment in severe maceration increased the energy consumption. However, the extra energy consumption is compensated for by a higher proportion of the protein concentrate. The process still needs to be optimized to reduce the protein loss in the brown juice and increase the protein concentrate yield. In addition, it is highly recommended to use high-quality biomasses with high protein content.