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# The effect of harvest time of ensiled whole crop field pea or faba bean on their composition and *in vivo* digestibility

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This study evaluated the botanical, morphological and chemical composition of pea-wheat (PW) and faba bean-wheat (FBW) whole crop herbages at different harvest times at 2-week intervals in Northern Finland. The herbages were also ensiled in round bales and their *in vivo* digestibility was measured using the total faecal collection method with sheep. The grain legumes dominated in the stands so that the proportions of pea and faba bean were on average 0.912 and 0.824 (on dry matter (DM) basis). The harvest time affected the organic matter digestibility of the crops differently as it decreased for PW but increased for FBW with progressing growth. The average *in vivo* D-values of the silages were rather low (581 and 595 g kg<sup>-1</sup> DM for PW and FBW, respectively). *In vitro* pepsin-cellulase digestibility predicted *in vivo* organic matter digestibility moderately well (R<sup>2</sup>=0.54), but the data set was small. Ensiled whole-crop cereal silages dominated by grain legumes showed potential as feeds for cattle.

**Key words:** *in vitro* digestibility, indigestible neutral detergent fibre, whole crop cereal silage, *Vicia faba*, *Pisum sativum*

## Introduction

Although maize silage use is still rare under the Boreal conditions of Finland (Rinne et al. 2024), whole crop silages from small grain cereals have shown good potential in cattle feeding when supplementing (Jaakkola et al. 2009, Huuskonen et al. 2020) or replacing (Huuskonen and Joki-Tokola 2010, Huuskonen et al. 2017) grass silage. Whole crop cereal silages can be harvested with the same machinery as grass silage and high dry matter (DM) yield is obtained by a single harvest during the growing season (Powell 2008).

Since the protein content of cereals is low (Luke 2025a), inclusion of grain legumes to seed mixture offers an opportunity to increase the feed value of whole-crop cereal silages (Pursiainen and Tuori 2006, Kuoppala et al. 2014, Kamalongo and Cannon 2020, Angeletti et al. 2022). Use of legumes in crop mixtures also decreases the need of nitrogen (N) fertilizers due to the ability of legumes to utilize atmospheric N via biological N fixation (Phelan et al. 2015). Furthermore, choosing optimal harvest time is more flexible when using mixtures of legume and cereal crops than sole crops (Powell 2008). Cannon et al. (2019) concluded that intercropping of faba bean and spring wheat can increase the DM yield per hectare. Similarly, Ghanbari-Bonjar et al. (2003) reported higher yields of faba bean wheat intercrops than faba bean or wheat as sole crops. Intercropping also decreased weeds compared with sole cropping and according to Cannon et al. (2019), intercropping can serve as a non-chemical weed management. An additional benefit is that dryer cereal component in a mixture containing legumes can at least partly decrease the formation of effluent in ensiling (Angeletti et al. 2022).

Whole crop cereal silages are typically used as a component in diets including also other forages and concentrate components. Feeding trials using dairy cows (Markkanen 2014, Lamminen et al. 2015, Palmio et al. 2022) and growing beef cattle (Huuskonen et al. 2016) have shown positive responses of including whole crop silages from grain legumes into the diets.

In Nordic countries faba bean (*Vicia faba*), field pea (*Pisum sativum*), common vetch (*Vicia sativa*) and hairy vetch (*Vicia villosa*) are commonly used annual forage legumes (Huuskonen et al. 2016). In spite of the growing interest to produce domestic protein by using legumes, the cultivation area of pea and faba bean in Finland is very small, only 2.5 % of total cultivated area (Luke 2025b). The harvested area of pea has increased recently while that of faba bean has decreased the areas being 44 500 ha for pea and 6 300 ha for faba bean in 2025 (Luke 2025b). Pea area has increased mainly because of the increased use of it as protein supplement for livestock to replace imported protein supplements. On average 9 and 5 % from total harvested area of pure pea and faba bean, respectively, is harvested as whole crop silage. Data of mixed crops is difficult to extract from the statistics as harvesting methods (ensiled or combine harvested) is not specified.

To optimize the production of legume-cereal whole crop silages and their use in ruminant rations, reliable information is needed about the effect of harvest time of crop mixtures and the feeding value of the respective silages. Forage digestibility is the single most important factor affecting feed intake and subsequent production responses of dairy cows (Huhtanen et al. 2007). For ration formulation purposes, a fast and reliable determination of forage digestibility is critical. One challenge related to whole crop legume silages has been the limited knowledge about the reliability of feed value determinations as e.g. in the data set of Huhtanen et al. (2026) there were no data of such feeds. The golden standard of the digestibility measurement of ruminant feeds is the total faecal collection method using sheep at maintenance level. When the same feeds are analysed using laboratory methods, the accuracy of laboratory methods can be assessed and improved (Huhtanen et al. 2006).

The aim of this experiment was to describe the effect of harvest time on chemical, botanical and morphological composition, digestibility and feed values of whole crop herbage and silages of faba bean and field pea intercropped with wheat. We specifically wanted to evaluate how the current *in vitro* digestibility methodology based on pepsin-cellulase solubility (Nousiainen et al. 2003) can detect the quality of the whole crop silages. The samples and silages in the current experiment were prepared from the same fields as the silages in the feeding trial of growing and finishing bulls reported by Huuskonen et al. (2016). The effect of different silage additives on preservation parameters was investigated simultaneously in a laboratory scale silage experiment (Seppälä et al. 2019).

## Material and methods

### Production and analysis of herbage

Two legume-cereal mixtures field pea (*Pisum sativum*, cv. Florida) + wheat (*Triticum aestivum*, cv. Anniina) (PW) and faba bean (*Vicia faba*, cv. Fuego) + wheat (cv. Anniina) (FBW) were cultivated in 4.1 and 4.9 ha areas, respectively, on adjacent fields at the experimental farm of Natural Resources Institute Finland (Luke) in Ruukki (64°44'N, 25°15'E), Finland. The fields of PW and FBW were sown on 6–10 June and 4–5 June 2013, respectively. The amounts of seeds per hectare were 138 kg of field pea + 75 kg wheat and 174 kg faba bean + 75 kg wheat. Sowing depths were 6–8 cm and 2–3 cm for legumes and cereals, respectively. Wheat was sown one day later than the grain legumes. Before sowing the PW field received cattle slurry at 22 t ha<sup>-1</sup>, while the FBW field received composted cattle manure at 14 t ha<sup>-1</sup>. The amounts of nutrients delivered were 37–6–40 kg and 50–27–61 kg of N-P-K per ha for PW and FBW, respectively. All nutrients were given as slurry or manure, and no chemical fertilizers were used. No inoculation of legume seeds with N-fixation bacteria was used.

Biomass samples were collected three times from both fields at two-week intervals at approximately 10, 12 and 14 weeks after sowing (14 August, 27 August and 11 September at 2013) using Haldrup plot harvester (Haldrup GmbH, Ilshofe, Germany). At the first harvest date, a strip was mown using a disc mower in the middle of the field. Then four randomly chosen sites (circa 12 m<sup>2</sup> per site) along that strip were harvested for sampling using Haldrup. At the following harvest dates, the Haldrup strips were taken next to the ones harvested at the first sampling date. The biomass yield was weighed using the Haldrup harvester separately at all four sites per field. The four intact biomass samples were analysed for DM and botanised by manually separating the sample to legumes, wheat and other plants. Morphological analysis, where leaves, stems and pods of pea and faba bean were separated manually, as well as chemical analyses were conducted on pooled samples of each harvest time and field, respectively.

### Preparation of silages

The two legume-cereal mixtures were harvested for silage at the same three occasions as the herbage sampling occurred. The stands were mown with Elho 280 Hydro Balance disc mower with tine conditioner (El-Ho Ltd, Pännäinen, Finland) and harvested after a wilting period of 2–3 hours using an integrated baler wrapper (Machale Fusion 2, McHale, Ballinrobe, Ireland). The silages were preserved with a formic and propionic acid-based additive (AIV Ässä [FPA]), Eastman, Oulu, Finland; formic acid 590, propionic acid 200, ammonium formate 40, potassium sorbate 25 g kg<sup>-1</sup>) using 6 litres per ton. The bales were opened after 90 days of preservation and shredded in a mixer wagon. Subjective observations confirmed excretion of effluent from the bales but the amount of it was not measured. The shredded feed was stored frozen (–20 °C) in smaller batches for the digestibility trial.

## *In vivo* digestibility trial

Apparent *in vivo* digestibility of the six silages was measured as described by Rinne et al. (2016). In brief, six 1-year old Finnsheep rams were used in a digestibility trial using the total faecal collection method at Luke Jokioinen during spring 2014. The animals were managed according to Finnish legislation regarding the use of animals in scientific experimentation. The experimental model was an incomplete  $6 \times 5$  Latin square with two plant mixtures (PW and FBW), three harvest times (10, 12 and 14 weeks after sowing) and five periods. Each experimental period lasted for 14 days from which the last 5 days were the collection period with total collection of faeces and urine. The animals were kept in digestibility cages during the 5-day collection period, while during the preceding adaptation period they were kept in larger individual pens (2.50 m  $\times$  2.25 m). The daily ration of the rams consisted of either PW or FBW silages supplemented with 30 g mineral mixture and 10 g NaCl. Water was available *ad libitum*. The amount of silage fed was 41 g DM kg<sup>-1</sup> metabolic live weight, calculated based on the live weight of each ram measured at the beginning of the collection week. Two observations (one for PW1 and one for FBW1) were removed from the data set due to problems with animal health that were assumed not to be related to experimental treatments. The feed portions were weighed according to the DM concentration determined prior to the collection period. The silages were thawed just before feeding. Most silage effluent was drained before delivering the feed to the sheep but the amount was not measured. The DM determination of the silages was conducted from the drained feed. Sub-samples of silages and faeces were taken daily during each collection period, pooled by ram and period and stored at  $-20^{\circ}\text{C}$  prior to analyses.

## Chemical analyses and calculations

Intact, botanical and morphological samples of the herbage as well as thawed silage and faecal samples were analysed for DM, ash, crude protein (CP), starch and neutral detergent fibre (NDF) as described by Seppälä et al. (2016). Silage samples were also analysed for fermentation quality (for methods, see Seppälä et al. 2016). The *in vitro* pepsin-cellulase solubility (OMS) was determined as described by Nousiainen et al. (2003) and used to calculate digestibility of organic matter ( $\text{OMD}_{\text{VITRO}}$ ) according to Huhtanen et al. (2006). Indigestible NDF (iNDF) concentration was determined by a 12-d rumen incubation in polyester bags according to Krizsan et al. (2015). The metabolizable energy (ME) concentration of silages was calculated as  $0.0155 \text{ MJ g}^{-1} \times \text{D-value (g kg}^{-1} \text{ DM)}$ . The ME coefficient was for whole crop silages and the D-value was derived from  $\text{OMD}_{\text{VITRO}}$ . Metabolizable protein concentrations as well as protein balance in the rumen were calculated according to the Finnish feed evaluation system (Luke 2025a). Cell solubles were calculated as “DM minus NDF” and potentially digestible NDF as “NDF minus iNDF”. The relationships between the *in vivo* and *in vitro* digestibility values were evaluated using regression analysis by MS Excel.

## Statistical analysis

The data were analysed statistically using MIXED procedure of SAS (version 9.4., SAS Institute Inc., Cary, NC, USA.). The model for herbage included species and harvest time as fixed effects while replicate was used as a random variable. *In vivo* silage digestibilities were analysed using species, harvest time and period as fixed effects and animal as the random variable. The results are shown as least squares means for DM yield and botanical proportions of legumes and wheat in the crop mixtures as well as for *in vivo* digestibilities. Differences between the treatments were tested using orthogonal contrasts: (1) PW vs. FBW, (2) linear effect of harvest time, (3) quadratic effect of harvest time, (4) interaction between (1) and (2), and (5) interaction between (1) and (3). The quadratic effect of harvest time as well as the interaction of it with plant species were omitted from the Tables due to non-significant *p*-values. As no replication of botanical and morphological fractions was conducted, they are presented as descriptive data.

## Results

### Herbage characteristics

Both crop mixtures had low DM concentrations with an average of 194 and 169 g kg<sup>-1</sup> for PW and FBW, respectively (Table 1). DM concentration increased linearly with postponed harvest the effect being more pronounced for PW compared with FBW (*p* for species $\times$ time < 0.01). The DM yield of PW increased by 68 kg DM ha<sup>-1</sup> per day and was 6954 kg ha<sup>-1</sup> at the last harvest. The FBW tended to be more productive than PW (*p* = 0.092), with a daily increase of 151 kg DM ha<sup>-1</sup> and a final harvest of 8970 kg DM ha<sup>-1</sup>. Major part of both crop mixtures were legumes, as the average proportions of wheat were only 8.8% and 15.8% for PW and FBW, respectively. The botanical proportions did not change with harvest time. The crop mixtures were so dense that the proportion of other plant species was very low although slightly higher in FBW than in PW (*p* < 0.01).

Table 1. Effect of harvest time (1, 2 and 3) on the growing time characteristics, yield, proportions of the plant species in the mixture, and the chemical composition of mixtures of faba bean+wheat (FBW) and field pea+wheat (PW) herbage

	PW			FBW			SEM <sup>1</sup>	p-values <sup>2</sup>		
	1	2	3	1	2	3		Species (S)	Time (L)	S × L
Harvest date	Aug 14	Aug 27	Sep 11	Aug 14	Aug 27	Sep 11				
Weeks from sowing	10	12	14	10	12	14				
Temperature sum from sowing, degree days, °Cd	633	808	918	675	850	960				
Rainfall sum from sowing, mm	141	179	187	170	208	216				
Number of samples	4	4	4	4	4	4				
Dry matter, g/kg	139	200	243	149	169	188	0.9	0.003	<0.001	0.002
Dry matter yield, kg/ha	5038	6839	6954	4750	7009	8970	440.7	0.092	<0.001	0.017
Proportion in mixture (on dry matter basis)										
Legume	0.916	0.892	0.927	0.778	0.837	0.858	0.0290	0.002	0.129	0.245
Wheat	0.084	0.107	0.073	0.196	0.149	0.128	0.0271	0.005	0.155	0.301
Other plants	0	0.002	0	0.026	0.014	0.014	0.0060	0.002	0.300	0.300

<sup>1</sup>Standard error of the mean; <sup>2</sup>Orthogonal contrasts: Species = PW vs. FBW, Time = linear effect of harvest time, S × L = Interaction of S and L

The morphological composition of the grain legumes is presented in Table 2. The proportion of leaves decreased with progressing growth but less in pea than in faba bean. For both crops, proportion of stems decreased while that of pods increased with time. Leaves contained more ash and protein than pods and stems for both species. The CP concentration of the leaves remained quite stable at different harvest times, while that of the pods and stems decreased slightly in faba bean but not with in pea. Starch was mainly found in the pods and the concentration of it increased with progressing time. Stems were clearly the most fibrous (NDF and iNDF) fraction. Pods had the highest and stems the lowest OMD<sub>VITRO</sub>.

Table 2. Descriptive data of the effect of harvest time on the proportion and the chemical composition of leaves, pods and stems in whole plants of faba bean and field pea in faba bean+wheat and pea+wheat mixtures

Harvest time	Leaves			Stems			Pods		
	1	2	3	1	2	3	1	2	3
Field pea									
Dry matter (DM), g kg <sup>-1</sup>	138	206	293	157	208	237	128	157	178
Proportion (on DM basis)	0.229	0.214	0.174	0.595	0.474	0.410	0.176	0.311	0.415
In DM, g kg <sup>-1</sup>									
Ash	105	103	113	65	62	66	54	49	54
Crude protein	306	310	308	121	118	123	248	238	250
Starch	26	33	36	33	37	32	102	138	161
Neutral detergent fibre (NDF)	217	219	232	526	523	559	241	269	253
Indigestible NDF	36	25	51	312	317	335	35	38	43
<i>In vitro</i> D-value	739	739	675	547	547	516	849	850	842
<i>In vitro</i> pepsin-cellulase solubility	0.882	0.880	0.809	0.613	0.611	0.576	0.963	0.959	0.956
<i>In vitro</i> organic matter digestibility	0.825	0.824	0.760	0.585	0.584	0.552	0.897	0.893	0.891
Faba bean									
Dry matter, g kg <sup>-1</sup>	137	153	149	152	186	211	108	125	161
Proportion (on DM basis)	0.381	0.293	0.154	0.501	0.442	0.437	0.118	0.265	0.409
In DM, g kg <sup>-1</sup>									
Ash	115	115	112	62	54	46	67	58	47
Crude protein	303	305	300	93	80	67	280	250	241
Starch	23	49	44	37	57	83	154	191	180
NDF	194	204	190	522	550	510	192	236	224
iNDF	35	36	36	274	331	325	18	26	25
<i>In vitro</i> D-value	752	737	742	565	534	553	807	801	818
<i>In vitro</i> pepsin-cellulase solubility	0.909	0.891	0.894	0.632	0.589	0.606	0.927	0.911	0.919
<i>In vitro</i> organic matter digestibility	0.849	0.833	0.836	0.602	0.564	0.579	0.865	0.851	0.858

The average CP concentrations were higher in PW than in FBW (191 vs. 179 g kg<sup>-1</sup> DM) but starch concentrations were lower in PW than in FBW (55 vs. 99 g kg<sup>-1</sup> DM) for herbage as presented in Table 3. The starch concentration was very low at the first harvest and increased thereafter the change being greater in FBW than PW. The NDF and iNDF concentrations were lower and OMD<sub>VITRO</sub> higher in FBW than in PW and they remained rather stable over the harvest times.

### Silage characteristics

In spite of the higher DM concentration of silages (on average 231 g kg<sup>-1</sup>) compared with the respective herbage (on average 181 g kg<sup>-1</sup>), the DM concentration of silages was still very low (Table 3). In general, the composition of the silages reflected that of the herbage, but concentrations of soluble nutrients (ash, CP) were lower while that of NDF was higher. The CP concentration was higher in PW than in FBW and it increased with postponed harvest. The concentration of NDF was slightly higher for FBW than PW being lowest for the 3<sup>rd</sup> harvest for both. Concentration of iNDF was higher for PW than FBW with no change with postponed harvest. At the 3<sup>rd</sup> harvest, the iNDF concentration was clearly lowest for FBW.

Table 3. Descriptive data of the effect of harvest time (1, 2 and 3) on the chemical composition and fermentation quality of field pea+wheat (PW) and faba bean+wheat (FBW) herbage and silages

	PW			FBW		
	1	2	3	1	2	3
Herbage						
Dry matter (DM), g kg <sup>-1</sup>	139	200	243	149	169	188
Chemical composition, g kg <sup>-1</sup> DM						
Ash	79	75	74	81	76	68
Crude protein	188	192	193	188	179	170
Starch	37	38	90	42	119	135
Neutral detergent fibre (NDF)	423	417	412	387	378	396
Indigestible NDF (iNDF)	180	207	179	153	151	167
<i>In vitro</i> D-value	641	626	647	653	660	658
<i>In vitro</i> pepsin-cellulase solubility	0.678	0.679	0.663	0.658	0.659	0.720
<i>In vitro</i> organic matter digestibility	0.696	0.677	0.698	0.710	0.714	0.706
Silage						
DM, g kg <sup>-1</sup>	200	218	270	215	230	251
Chemical composition, g kg <sup>-1</sup> DM						
Ash	71	74	82	86	64	63
Crude protein	164	172	181	144	161	166
Water soluble carbohydrates	67	53	54	53	71	90
NDF	504	482	479	513	516	457
iNDF	220	224	224	203	199	170
<i>In vitro</i> D-value	598	596	578	571	586	638
<i>In vitro</i> pepsin-cellulase solubility	0.678	0.679	0.663	0.658	0.659	0.720
<i>In vitro</i> organic matter digestibility	0.644	0.644	0.630	0.625	0.626	0.681
Metabolizable energy, MJ kg <sup>-1</sup> DM	9.3	9.2	9.0	8.9	9.1	9.9
Metabolizable protein, g kg <sup>-1</sup> DM	72	76	76	71	74	80
Protein balance in the rumen, g kg <sup>-1</sup> DM	52	60	70	39	51	48
Fermentation products, g kg <sup>-1</sup> DM						
Lactic acid	72	92	74	66	43	26
Acetic acid	9.1	13.7	13.0	10.7	10.1	7.7
Propionic acid	3.6	3.4	3.1	3.3	4.2	3.2
Butyric acid	0.6	0.6	0.4	0.5	0.5	0.5
Ethanol	2.3	5.8	4.2	3.2	1.9	4.8
Total fermentation products	88	116	95	84	60	42
pH	3.96	4.03	4.21	4.00	4.00	4.21
Ammonium-N, g kg <sup>-1</sup> N	72	92	87	53	51	49
Soluble N, g kg <sup>-1</sup> N	617	602	589	554	504	475

## In vivo digestibility

The *in vivo* digestibility of the PW and FBW silages is presented in Table 4. The harvest time affected the digestibilities of DM, OM, NDF and cell solubles of PW and FBW differently as for PW, the digestibilities decreased while those of FBW increased with progressing growth ( $p$  for species $\times$ time < 0.01). The OM, cell solubles and pdNDF digestibilities were higher while those of CP and pdNDF lower in FBW than PW ( $p$  < 0.05). The NDF digestibility did not differ between the species. The *in vitro* OMS and iNDF concentration correlated moderately with the *in vivo* OMD values ( $R^2 = 0.54$  and  $0.40$ , respectively).

Table 4. The effect of harvest time (1, 2 and 3) on the *in vivo* digestibility ( $\text{g g}^{-1}$ ) of field pea+wheat (PW) and faba bean (FBW) silages

	PW			FBW			SEM <sup>1</sup>	$p$ -values <sup>2</sup>		
	1	2	3	1	2	3		Species (S)	Time (L)	S $\times$ L
Number of observations	4	5	5	4	5	5				
Dry matter (DM)	0.631	0.615	0.593	0.603	0.617	0.643	0.0047	0.069	0.847	<0.001
Organic matter	0.651	0.630	0.605	0.630	0.629	0.661	0.0048	0.015	0.15	<0.001
D-value, $\text{g kg}^{-1}$ DM	605	584	555	576	589	619	4.3	0.003	0.494	<0.001
Crude protein	0.756	0.738	0.720	0.690	0.695	0.689	0.0117	0.001	0.167	0.174
Cell solubles	0.746	0.739	0.711	0.744	0.743	0.761	0.007	0.017	0.267	0.005
Neutral detergent fibre (NDF)	0.568	0.527	0.503	0.541	0.536	0.552	0.0105	0.276	0.037	0.006
Potentially digestible NDF	1.014	0.984	0.952	0.897	0.873	0.879	0.0146	<0.001	0.025	0.179

<sup>1</sup>Standard error of the mean of diets PW1 and FBW1 should be calculated by  $\text{SEM} \times 1.184$ ; <sup>2</sup>Orthogonal contrasts: Species = PW vs. FBW, Time = linear effect of harvesting time, S  $\times$  L = Interaction of S and L

## Discussion

### Herbage production

The low DM content of the herbage and silages can partly be explained by the high proportion of legumes in the crops, which was on average 91% in the PW and 82% in FBW on DM basis. This high proportion of the legumes was unexpected as in the previous year the same sowing density produced proportions of faba bean and pea of approximately 50% (Kuoppala et al. 2014). Warm weather during the sowing time and early summer may have favoured the growth of legumes so that wheat was outcompeted by them. One of the disadvantages of intercropping is that the percentage of each plant species cannot be predicted very accurately because the species may respond differently to the weather conditions that vary greatly between years. On the other hand, this can be considered an advantage as at least some species have high yield potential even though other species may underperform under particular weather conditions.

The average starch content of faba bean pods was higher than that of peas (175 vs. 133  $\text{g kg}^{-1}$  DM) which are still relatively low values compared e.g. to the Feed Table values of 380  $\text{g kg}^{-1}$  DM for faba bean and 480  $\text{g kg}^{-1}$  DM for pea (Luke 2025a). The varieties used in the current study were late maturing varieties targeted for whole crop production so that full ripening of the seeds was not even expected. Further, not just seeds but also the whole pods were included in this fraction.

The average NDF concentration in different morphological parts of the legume plant varied considerably. The proportion of iNDF from total NDF was high in stems (on average 0.60 in both plant species) but low in leaves and pods (leaves 0.18 and pods 0.13) reflecting their digestibility. At all harvest times, the concentration of iNDF was high in the stems (up to 335  $\text{g kg}^{-1}$  DM), while the concentrations in leaves and pods were low corresponding to those of early harvested grass material (Kuoppala 2010).

### Effect of harvest time

For grass silages, the timing of harvest has a crucial and well documented effect on digestibility under Boreal conditions (e.g. Kuoppala et al. 2008). For whole crop cereals, the phenomenon is quite different as the plants at harvest are approaching full maturity with increasing proportion of nutritionally high-quality seeds, and the trends in digestibility development can be variable or even non-existent (Kuoppala et al. 2017). Optimal harvest time of legume cereal crop mixtures is a balance between yield, digestibility and harvesting losses, with additional restrictions including prevailing weather conditions and labour availability.

As growth progressed, the proportion of leaves in the total plant mass decreased and the proportion of stems and pods increased. The leaves of legumes are rich in protein and have good digestibility, while the stem is woody, low in protein and digestibility. The DM and starch concentrations of legumes increases as the seeds develop in the pods, i.e. as the pods fill up (Kuoppala et al. 2014). By harvesting late, it is possible to maximize the DM and CP yields, but at least with late ripening varieties, digestibility also remains moderate for a long time (Palmio et al. 2022). Digestibility of OM in FBW was highest at latest harvest time similarly as in the plot experiment of Kuoppala et al. (2014). The optimal time for harvest would probably be when the leaves are still green, and the pods are full but not fully ripen yet. That stage was obtained earlier in PW than in FBW. The weather conditions at the time of cultivation, the legume and cereal varieties grown, and the harvesting method all affect the optimal harvest time.

The feed value of the crop at the time of harvest sets an upper limit on the quality of the feed, as even successful preservation slightly impairs the quality of the feed. Under challenging preservation conditions (rain during pre-drying, abundant effluent excretion, poor fermentation), the decline in highly digestible nutrients and thus digestibility can be excessive. In this experiment, the herbage OMS was on average 52 g kg<sup>-1</sup> higher than the corresponding silage, indicating considerable preservation losses. In well preserved grass silages, the loss of digestibility was only 24 g kg<sup>-1</sup> (Huhtanen et al. 2005). A significant part of digestibility loss in the current silages was due to the losses of valuable nutrients such as sugars and proteins in the effluent. In addition, the extent fermentation was also high resulting in fermentation losses in the form of CO<sub>2</sub> (McDonald et al. 1991). The amount of effluent could not be determined from bales, but the DM concentration of the raw materials was on average 181 g kg<sup>-1</sup> while that of silages 231 g kg<sup>-1</sup>, i.e. the silages were clearly drier than the raw materials. Part of the DM difference is due to the 2–3 h field wilting in addition to effluent losses.

### Silage characteristics

One reason for the low DM concentration of the silages was the low proportion of wheat in both crop mixtures. Higher proportion of wheat in the crop mixtures could have decreased the amount of effluent as described by Angeletti et al. (2022). A longer wilting period instead of 2–3 hours on the field could have alleviated the loss of nutrients as effluent but was not possible for practical reasons. However, high DM concentration of intercropped faba bean + wheat has been obtained under Finnish conditions as reported by Lamminen et al. (2015). They used faba bean cv. Kontu and reached a DM concentration of almost 400 g kg<sup>-1</sup>. In that experiment the faba bean had reached a higher level of ripening at harvest and wilting conditions were good in July in southern Finland. However, the relative humidity in autumn is high and the possibilities for successful wilting are challenging especially in northern Finland.

Whole crop cereal silages are typically relatively easy to ensile due to high DM concentration and low buffering capacity, but high inclusion of grain legumes in the herbage makes the ensiling more challenging (McDonald et al. 1991). Fermentation quality characteristics of the PW and FBW silages were typical for moist feeds, i.e. pH was low and lactic acid concentration high. However, there were so much water soluble carbohydrates left in all silages that lack of substrate had not restricted lactic acid formation. Proportion of ammonia N in total N was somewhat elevated in PW silages (on average 84 g kg<sup>-1</sup> N) indicating that the preservation was not entirely successful (McDonald et al. 1991).

The herbage of harvest time 2 were also used for an ensiling trial using silage additives of different modes of action (Seppälä et al. 2019). Due to the high WSC concentration of the crop prior to ensiling (156 and 176 g kg<sup>-1</sup> DM for PW and FBW, respectively), all silages (untreated, lactic acid bacteria inoculant treated and FPA treated) could be classified as well preserved according to the low pH and butyric acid concentration. The use of FPA dramatically reduced the extent of fermentation in FBW with a mean of total fermentation products of 43 g kg<sup>-1</sup> compared to a mean of 177 g kg<sup>-1</sup> DM for the other treatments. For PW, the acid additive was not able to effectively restrict fermentation as concentration of fermentation products for acid treatment was 179 g kg<sup>-1</sup> DM and for other treatments 196 g kg<sup>-1</sup> DM. Such high concentrations of fermentation products would be likely to reduce the feed intake of silages (Huhtanen et al. 2007).

The same FPA additive as by Seppälä et al. (2019) was used in the current experiment, but with a slightly higher dose (6 vs. 5 litres/ton fresh material). It seems that the use of farm scale ensiling in round bales resulted in somewhat different type of preservation than in laboratory scale ensiling. The greatest differences were the extensive ethanol production in PW and the more restricted fermentation of FBW at laboratory scale compared to the round bales of the current experiment, which also had slightly higher DM concentration than the laboratory silos most likely due to greater effluent losses from the bales.

Again, the same plant material was used to prepare silages for a feeding trial for growing bulls (Huuskonen et al. 2016) and the crops were ensiled in large bunker silos. The DM concentrations of the bunker silages were as high as 269 and 277 g kg<sup>-1</sup> for PW and FBW, respectively, and amounts of total fermentation products were 73 and 84 g kg<sup>-1</sup> DM. In this case, silage analyses were conducted in a commercial feed laboratory (Valio Ltd., Seinäjoki, Finland) so the methodology also differed. These comparisons highlight that the same silage raw material may result in different fermentation characteristics depending directly and indirectly (e.g. through excretion of silage effluent) on the preservation method.

### Estimation of silage *in vivo* digestibility using laboratory analyses

*In vitro* pepsin-cellulase solubility and iNDF concentration have shown good relationships with *in vivo* digestibility for grass and forage legume silages (Huhtanen et al. 2006), but the data set used for the correction equations did not contain any whole crop grain legume silages. Figure 1 shows the relationships of OMS and iNDF with the *in vivo* OMD of the current data, and relationships for other forage types reported by Huhtanen et al. (2006) are included for comparison. In the current data set, both accuracy and precision of OMD prediction seemed to be better with OMS than with iNDF. For iNDF, all the data points showed higher digestibility at a certain iNDF concentration than the previously estimated equations but were closest to the relationship of forage legumes. It is important to highlight that the current data set is very small, and the results need to be considered indicative.

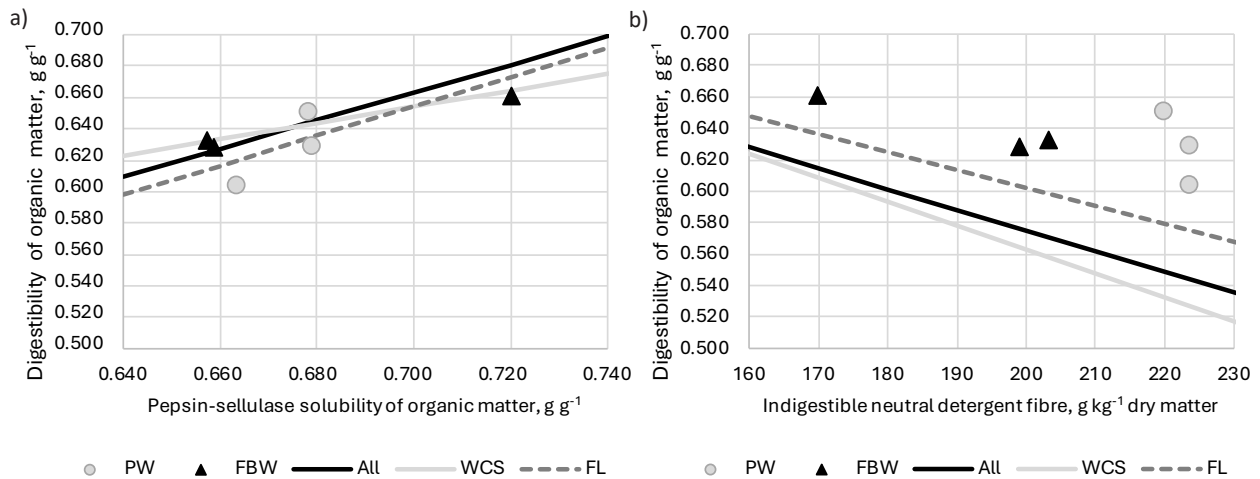


Fig. 1. Relationships between silage *in vivo* organic matter digestibility (OMD) and pepsin-cellulase solubility (OMS; a) and indigestible neutral detergent fibre (iNDF; b) of pea-wheat (PW) and faba bean-wheat (FBW). The lines represent the respective relationship reported by Huhtanen et al. (2006) for the whole data set (All), whole crop cereal silages (WCS) and forage legumes (FL).

The need for separate correction equations for different plant materials stems from fundamental differences between the *in vivo* and *in vitro* digestibility determination approaches. In the *in vitro* procedure, there is no production of metabolic and endogenous material like in the digestive tract of a ruminant which means that the *in vitro* digestibility represents true digestibility while the *in vivo* digestibility is apparent. Further, the rumen of sheep at maintenance level is more efficient in digesting fibre than the *in vitro* pepsin-cellulase solubilization. Thus, when different plant materials differ in proportions of cell wall and cell solubles, the relationships between OMS and OMD<sub>*in vivo*</sub> differ. This is visible in Figure 1a, where forage legumes have lower OMD<sub>*in vivo*</sub> than the whole data set at the same OMS as legumes in general have lower NDF concentration than grasses (Huhtanen et al. 2006). Since the proportion of wheat was so low in the current silages, the results can be considered to represent grain legumes.

The cell wall structure of legumes is different from gramineous plant species (grasses, cereals) as the iNDF concentration in the cell walls of legumes is higher but concentrated around xylem stratum of legume stems (Wilson and Kennedy 1996). Other legume stem strata contain no or very little iNDF so that the linkages with cellulose are not so extensive (Wilson and Kennedy 1996) making the negative effect of iNDF on cell wall digestibility as indicated in Figure 1b. This seems to be the case for the current PW and FBW silages as well so that they resemble more the forage legumes than the whole crop cereal silages in the relationship between iNDF concentration and OMD<sub>*in vivo*</sub>. It is obvious that the number of observations in the current data set is very limited, which precludes making definite conclusions.

## Conclusions

Whole crop cereal silages typically have low OMD, and inclusion of grain legumes may not be able to alleviate that as their inherent OMD also tends to be lower than that of grasses harvested at optimal stage of maturity. A high proportion of legumes may result in low herbage DM concentration particularly under humid weather conditions during the harvesting so that higher proportion of cereals could be beneficial in e.g. avoiding silage effluent losses and risk of poor fermentation quality. The unpredictable proportions of different plant species in the mixture require careful evaluation of the feed quality for ration formulation.

The current results indicate that *in vitro* pepsin-cellulase solubility and iNDF concentration have potential to be used as indicators of *in vivo* digestibility of whole crop pea and faba bean silages. The relationship between laboratory analyses and *in vivo* digestibility seems to be closer to that of forage legumes than to whole crop small grain cereal silages, but the data of the current data set is very limited, and more observations would be needed to fully conclude on this.

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