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Incorporating crop rotation and malted faba beans to enhance beer sustainability

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Abstract

Why was the work done: The brewing industry faces growing challenges from stricter regulations and from climate change, driving the need for sustainable innovation. One approach is the use of legumes as brewing adjuncts, given their low carbon footprint and ability to fix atmospheric nitrogen in soil. Incorporating diverse crops, such as barley, wheat, oats, and faba bean, promotes regenerative agriculture but also broadens raw material use in brewing. With the aim of promoting regenerative agriculture and sustainability in brewing, this study explores a 'crop rotation' beer made from barley, wheat, oats, and faba bean.
How was the work done: The use of malt bills including barley, wheat, oats, and faba bean would support crop rotation and diversify raw materials. Faba bean was incorporated in both a raw and malted form. Brewing was performed at both laboratory and pilot scale, and the physicochemical and sensory properties of the beers were evaluated in comparison to barley malt beers.
What are the main findings: The results show that crop rotation worts made with malted faba beans (Sprau®) were superior to raw faba beans with improved maltose levels, greater free amino nitrogen, and more protein, alongside lower polyphenol concentration. Further, pilot scale crop rotation beers brewed with Sprau® and its starch fraction achieved a more balanced flavour profile and higher ratings for taste, aroma, and overall quality, compared to those brewed with raw faba beans. The quality scores of the beers containing Sprau® were considered 'good' (>6) and on par with those observed with commercial malted barley beer.
Why is the work important: A 'crop rotation' beer, utilising malt made from four different crops, can be produced with similar physicochemical and sensory properties to beer from malted barley. Incorporating legumes in the malt bill supports sustainable farming practices, enhances biodiversity, and reduces reliance on cereal grains such as barley. Compared to raw faba beans, malted faba beans (Sprau®) exhibited superior physicochemical, functional, and sensorial properties, making them more suitable for brewing application. Therefore, incorporating malted legumes can yield beers with a balanced flavour profile and this offers brewers new alternatives for improving the sustainability of their products.

Keywords

Malt, cereal, legume, faba bean, biodiversity, sustainability, crop rotation

Introduction

The European brewing industry is facing significant challenges, notably the impact of climate change on agriculture and the tightening of governmental regulations (Brewers of Europe 2023). Such challenges demand innovative solutions and a strategic shift toward sustainable practices. One promising approach is the incorporation of legumes as eco-friendly adjuncts in brewing processes (Lienhardt et al. 2019; Black et al. 2021). Legumes have garnered attention from brewers and researchers due to their lower carbon footprint compared to barley. Further, legumes offer substantial potential for brewing applications given their rich nutritional composition, comprising of 60% starch, 25% proteins, and various bioactive compounds (Lienhardt et al. 2019; Black et al. 2021; Martineau-Côté et al. 2022; Deoghare et al. 2025). Moreover, unlike barley, legumes can fix atmospheric nitrogen, thereby enhancing soil quality and contributing to sustainable agricultural practices (Black et al. 2021).

Intensive farming has been developed to meet the needs of a growing population, but as a downside, soil has been cultivated to such a degree that its quality and productivity have diminished (European Environment Agency 2019). To reverse this trend, regenerative agriculture has emerged, with farming principles and practices that increase biodiversity, enriches soil, improves watersheds, and enhances ecosystems (Rhodes 2017). The faba bean (*Vicia faba*) has been shown to support a healthy soil ecosystem, such that inclusion in cropping systems improves soil fertility and encourages diversification (Duc et al. 2015). In addition, faba beans enhance the sustainability of cropping systems by fixing atmospheric nitrogen and increasing the soil organic matter (Karkanis et al. 2018). Further, faba beans host and feed pollinating insects (Köpke and Nemecek 2010).

One of the European Union Biodiversity Strategy for 2030 (https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en) key objectives is reversing the decline in genetic diversity. Currently, agriculture depends on a limited number of varieties designed for intensive farming. According to the Canadian International Development Research Centre (International Development Research Center 2010), wheat, rice, and maize provide more than 50% of the plant derived food energy in the world. Collectively, sorghum, millet, potatoes, sweet potatoes, soybean and sugar contribute another 25%. Pulses, however, occupy only 2.1 million hectares (10,000 square metres) in the EU, equivalent to about 4% of the area used for cereal grains (European Commission 2023). This is a significant opportunity to diversify crops by reintroducing underutilised species such as faba beans. By adopting crop rotation - the practice of regularly changing the crop grown in the same field over successive seasons to avoid continuous monoculture - it is possible to maintain soil fertility, reduce pests and disease, and foster more sustainable farming (Al-Musawi et al. 2025). Furthermore, incorporating legumes into the brewing industry can boost market demand for these crops, supporting a more diverse agricultural system.

The use of indigenous legumes, such as faba beans, have been explored in brewing (Black et al. 2019; 2021b; Deoghare et al. 2025). Studies have shown that worts containing 10-30% malted faba beans have extract yields comparable to those of barley while exhibiting improved free amino nitrogen (FAN) levels (Deoghare et al. 2025). However, incorporating 30% raw faba bean (dehulled flour) into the brewing process was reported to have a minor negative impact on the taste or acceptability of the resultant beer. (Black et al. 2019). Further, incorporating faba beans and other legumes into the process has also been associated with increased concentrations of 'green' volatile flavour compounds in the wort (Trummer et al. 2021; Deoghare et al. 2025). Such issues can be mitigated by extended wort boiling and fermentation with suitable microorganisms to decrease these off-flavour wort volatiles (Ritter et al. 2024).

In this study, the physicochemical and sensory characteristics of worts and their corresponding beers prepared using a malt bill designed around the 'crop rotation' concept. This consists of various cereal grains - barley, wheat, oat - and Sprau®, a commercially available malted faba bean. Pilsner malt (42%) and wheat malt (20%) were included as they contributed significant enzymatic activity to the mash. Malted faba bean Sprau® at 25% was chosen to make a difference to crop rotation, such that the beer would promote the cultivation of faba bean every 4-5 years. Oat Malt was also included to promote crop rotation, but the inclusion rate was kept low, as it impedes wort separation (Kordialik-Bogacka et al. 2014). Additionally, replacing Sprau® with raw faba bean flour, raw faba starch, or Sprau® starch was included for comparison. Brewing trials were conducted at both laboratory and pilot scale, with the resulting beers characterised by sensory analysis.

Materials and methods

For both laboratory and pilot scale trials, pale ale malt, caramel pale, dextrin malt, oat malt, wheat malt, Sprau® malted faba with shells, Sprau® starch, and raw faba bean with shell, were sourced from Viking Malt. Raw faba bean starch was sourced from Suomen Viljava Oy. Sprau® starch and raw faba bean starch was produced by dry fractionation and were starch-enriched rather than highly purified starch (Table 1).

Process - laboratory and pilot scale

At laboratory scale, beers were produced using a Congress Mash following Analytica EBC method 4.5.1 (Analytica EBC. 2004). Worts for each recipe (Table 2) were prepared using an LB Electronic automated mashing machine (LB Electronic, Berching, Germany). For each mash, the milled malts from each recipe were placed into a mashing cup, filled with 200 mL of distilled water preheated to 45°C. The cup containing the slurry was placed in the mashing machine, heated to 45°C, and stirred at 100 rpm for 30 min. The temperature was subsequently increased at a rate of 1°C per min until reaching 70°C, at which point an additional 100 mL of distilled water, preheated to 70°C, was added. This mixture was maintained at 70°C for 60 min. Each mash was prepared in duplicate.

The mash was cooled to 20°C and adjusted to 450 g with distilled water. Prior to filtration, 5 g of rice husk was added to each mash and transferred to funnels (20 cm diameter) lined with Whatman Grade 2V pre-folded filter paper (Whatman products, Cytiva, U.S.). For thorough extraction, 100 mL of the filtered wort was added back to the mashing cup and poured into the funnel. The filtration process took up to 120 min.

The wort filtration time for each malt type was analysed following the Analytica EBC 4.5.1 method and the wort volume was measured. Prior to fermentation each wort was boiled in 1 L Schott Duran bottles (DWL Life Sciences Gmbh, Germany) for 1 h in a water bath. Fermentations were conducted in triplicate with 300 mL of wort in a 500 mL Erlenmeyer flask with a glycerol-filled airlock. Yeast (*Saccharomyces cerevisiae* strain VTT A-75060) was pitched at 1 g fresh yeast/L of wort. The fermentations were performed at 20°C until mass loss stabilised or for a maximum duration of 7 days. Yeast was recovered by centrifugation at 9000 × *g* for 10 min at 10 °C.

The initial laboratory scale trials showed that beers brewed with Sprau® (malted faba bean) and its isolated starch fraction yielded higher ethanol levels than those brewed with raw faba beans and their starch fraction. To further assess these findings, three 90 L pilot scale batches were brewed at the Viking Malt Pilot Brewery (Finland), one using raw faba beans, and two using Sprau® and its starch fraction.

Pilot scale mashing and brewing were performed to produce ~12°P wort using a 200 L experimental brewhouse comprising a mash tun, lauter tun, wort kettle, whirlpool, plate heat exchanger, and a 100 L fermentation tank. For each brewing cycle, the

Table 1.

Composition and pasting temperature

Flours	Total starch %	Protein content %	Pasting temperature °C
Raw faba bean	$40.9^b \pm 4.2$	$33.9^a \pm 0.5$	$72.0^a \pm 0$
Raw faba starch-enriched	$56.8^a \pm 3.3$	$25.9^c \pm 0.1$	$71.2^b \pm 0$
Sprau®	$42.0^b \pm 0.4$	$33.6^a \pm 0.4$	$70.6^d \pm 0$
Sparu® starch-enriched	$59.2^a \pm 2.2$	$29.5^b \pm 0.1$	$70.6^c \pm 0$

Table 2.

Recipes used at laboratory and pilot scale.

Raw material	Laboratory scale Control 1	Laboratory scale Control 2	Laboratory scale **Beer 1** Pilot scale Beer **P1**	Laboratory scale **Beer 2** Pilot scale Beer **P2**	Laboratory scale **Beer 3** Pilot scale Beer **P3**	Laboratory scale **Beer 4**
Pale ale malt	66%	100%	42%	42%	42%	42%
Wheat malt	20%	–	20%	20%	20%	20%
Oat malt	5.2%	–	5.2%	5.2%	5.2%	5.2%
Caramel pale	4.4%	–	4.4%	4.4%	4.4%	4.4%
Dextrin malt	4.4%	–	4.4%	4.4%	4.4%	4.4%
Sprau® (Malted faba beans)	–	–	24%	–	–	–
Raw faba bean	–	–	–	24%	–	–
Sprau® starch	–	–	–	–	24%	–
Raw faba starch	–	–	–	–	–	24%

grist-to-water ratio was 1:5, targeting a 150 L pre-boil volume. For each recipe (Table 2), milled malts were mashed into water preheated to 55°C, held at 55°C for 20 min, then ramped (1°C/min) to 66°C for 30 min, followed by 73°C for 30 min, and finally heated to 77°C (mash-off) after 1 min. Rice hulls (15% w/w of grist) and $CaCl_2 \cdot 2H_2O$ (0.5 g/L) were added to facilitate wort separation. The wort was sparged in the lauter, boiled for 60 min with Cascade hops (6.6% α-acids; 83 g added at 60 min) and Citra hops (12.4% α-acids; 100 g added at 10 min), plus Protafloc (1 tablet, 15 min before the end of the boil). After the whirlpool and cooling to 20°C, US-05 ale yeast (0.77 g/L) (Fermentis, France) was pitched. Prior to fermentation, the wort was aerated for 2 x 1 min at 35 L air/min. Fermentations (90 L) were performed at 19°C for 7 days, followed by 4 days at 22°C and 7 days at 0°C. The beer was filtered through Beco K2 sheets (Eaton, Finland), kegged, force-carbonated at 5°C and 0.7 bar (~0.438% w/w), and stored at 8°C until analysis.

Pasting temperature using RVA analysis

Pasting temperatures were determined for raw faba, faba starch, Sprau® and Sprau® starch flours using a Rapid Viscosity-Analyzer model RVA-Super 4 (Newport Scientific, Warriewood, Australia) with the software program Thermocline for Windows (TCW). Each flour sample (3.5 g dry weight) was mixed with 25 g of distilled water in an RVA sample canister. The idle temperature was set at 40°C and a 26 min test profile was run as follows: (1) held at 40°C for 5 min (2) linearly ramped up to 95°C in 5.30 min, (3) held at 95°C for 5 min (4) linearly ramped down to 40°C in 5.30 min and (5) held at 40°C for 5 min. The pasting temperature was determined by inspection of individual viscogram curves to determine the time point (T1) at which the pasting viscosity began to increase. The pasting temperature was calculated by the formula PTm = (55/5.3) x (T1- 5) + 40.

Total starch content

The total starch content of raw faba, faba starch, Sprau® and Sprau® starch flours was determined using the Total Starch Assay Kit (AA/AMG), AOAC Method 996.11 from Megazyme Ltd (Germany).

Crude protein content

The nitrogen content of raw faba, faba starch, Sprau® and Sprau® starch flours was determined using the Dumas combustion method with a 'rapid MAX N exceed nitrogen and protein analyzer' (Elementar Analysensysteme GmbH, Germany). The nitrogen content of the samples was converted to crude protein content according to the formula: Protein content (%) = Nitrogen content (%) × 6.25

Wort and beer analysis

Following the mashing and brewing of faba bean based crop rotation recipes, the laboratory and pilot scale worts and beers were analysed at VTT (Finland) for their physicochemical differences, including fermentable sugars, ethanol, free amino nitrogen (FAN), protein, total polyphenols, and volatile aroma profiles. The pilot scale beers produced at the Viking Malt pilot brewery were evaluated using chemical and sensorial methods at VLB (Berlin).

Fermentable sugars and ethanol

Fermentable sugars (maltotriose, maltose, glucose, and fructose) in laboratory worts together with the ethanol concentration in the beers, were measured using High-Performance Liquid Chromatography (HPLC) using a Waters 2695 Separation Module and Waters System Interface Module liquid chromatograph coupled with a Waters 2414 differential refractometer (Waters Co., Milford, MA, USA). An Aminex HPX-87H Organic Acid Analysis Column (300 x 7.8 mm, Bio-Rad, USA) was equilibrated with 5 mM sulphuric acid (Titrisol, Merck, Germany) in water at 55°C, and samples were eluted with 5 mM H_2SO_4 in water at a 0.3 mL/min flow rate.

Free Amino Nitrogen

Free Amino Nitrogen (FAN) was measured using the EBC method (Analytica EBC wort 8.10.1. 2015). Ninhydrin colour reagent was prepared by dissolving 100 g of disodium hydrogen phosphate, 60 g potassium dihydrogen phosphate, 5 g ninhydrin, and 3 g fructose in 1L of distilled water. A glycine standard stock solution (100 mL) was made by dissolving 107.2 mg glycine in distilled water. For each assay, 1 mL of the glycine stock solution was diluted to 100 ml to give 2 mg amino nitrogen/L. A 'dilution solution' was prepared by dissolving 2 g potassium iodate in 600 mL distilled water, then adding 400 mL 96% (v/v) ethanol.

For the assay, sample (1 mL) was diluted to 50 mL with Milli-Q water (Millipore, Bedford, MA, USA), with 2 mL of diluted sample and 1 mL of the ninhydrin colour reagent was added to test tubes. Three control standards were also prepared by substituting 1 mL of glycine reagent for the wort in each standard. The tubes were heated in a boiling water bath for 16 minutes, then cooled in a cold water bath to 20°C within 20 min. Next, dilution solution (5 mL) was added and mixed, and the absorbance was measured at 570 nm against a blank containing 2 mL of Milli-Q water (Millipore, Bedford, MA, USA). All reagents were freshly prepared. FAN (mg/L) was calculated using the formula

$$FAN = \frac{A_1 \times 2 \times d}{A_2}$$

Where A_1 = absorbance at 570 nm, d = dilution factor and A_2= mean absorbance of glycine standards at 570 nm.

High molecular weight protein

Protein was measured using the Bradford method. For the assay, wort (50 µL) was mixed with 2.5 mL of Bio-Safe Coomassie Premixed Staining Solution (#1610787, Bio-Rad Finland Oy, Helsinki). After mixing, the absorbance was measured at 595 nm (Shimadzu UV-1800 spectrophotometer) between 10 and 40 min against a blank containing 50 µL of Milli-Q water (Millipore, Bedford, MA, USA). Protein concentration (mg/L) was determined using a standard curve prepared with bovine serum albumin (> 98% purity, Sigma Aldrich, USA).

Total polyphenol in wort

Total polyphenol in wort was determined using the standard EBC method (Analytica EBC beer 9.11. 2002) with modification where sample (10 mL) was added to a 50 ml falcon tube with 8 ml of CMC (carboxymethyl cellulose)/EDTA reagent. 0.5 ml of ferric reagent (3.5% ammonium iron citrate) was added, mixed and 0.5 ml of ammonia reagent (6% v/v aqueous ammonia solution) added and mixed. The mixture was then transferred to a 100 ml Duran bottle (DWK Life Sciences, UK).

The weight of the mixture was adjusted to 50 g with distilled water Milli-Q water (Millipore, Bedford, MA, USA), and mixed. After 10 min, the absorbance was measured at 600 nm against a blank prepared using 10 ml of sample, 8 ml CMC/EDTA reagent and 0.5 ml of ammonia reagent. Total polyphenol was determined from $P = A \times 820 \times 2$ where P represents the polyphenol concentration (mg/L) and A is the absorbance at 600 nm.

Volatile aroma compounds using GC/MS

The volatile aroma compounds in laboratory scale wort and beers were analysed using headspace solid phase micro-extraction coupled with gas chromatography (Agilent 7890A)-mass spectrometry (Agilent 5975C; HS-SPME-GC-MS) based on the method of Rodriguez-Bencomo et al (2012). Sample (200 µL), 1.8 g of NaCl, and 5 µL of internal standard solution (containing 52 ng 3-octanol, 58 ng 3,4-dimethylphenol) were added to 20 mL headspace vials. The samples were pre-incubated in Gerstel MPS autosampler at 44.8°C for 10 min and the volatiles extracted using a 2 cm divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) fibre (Supelco) at 44.8°C for 46.8 min. The samples were injected in splitless mode (10 min desorption time at 250°C), and the compounds were separated on an Restek Stabilwax-DA silica capillary column (60 m, 0.250 mm i.d., 0.25 µm film thickness). The temperature program of the oven was 50°C (2 min) to 240°C (6°C/min) and the final temperature was held for 11 min. The MS data were collected at a mass range of 25-500 amu. Identification was based on spectral data of reference compounds and those of NIST 08 library and peak area was normalised to that of the internal standards (3-octanol or 3,4-dimethylphenol).

Sensory analysis of beer

The pilot scale beers in kegs were supplied to VLB Berlin. Samples were dispensed into 0.5 L brown glass bottles, and the headspace purged with nitrogen before capping. After standing overnight, the sensory analysis of fresh beer was performed using quantitative descriptive analysis (QDA). The three beers were evaluated in a randomised order by 10 trained tasters who participated in all three sessions. All panellists perform sensory analysis of beer on a regular basis and were selected/trained as described in EBC Analytica 13.4. The tasting area, equipment, and glassware were in accordance with EBC Analytica 13.2. The samples were served at 8°C in cylindrical brown glasses and were coded with random three-digit codes. Each beer was tasted once, without replicates. The panellists were asked to first smell and then taste the samples. For aroma, the panellists were asked to scale the impression of both orthonasal and retronasal intensities for ten attributes (intensity of odour, cereal, hops, sweetness, estery/fruity, phenolic, solvent, sulphur, fatty, and oxidation) on a 9-point scale where the attribute is not present/intense ('1') to is strongly present/intense ('9'). The same scale was used for the intensity of taste and mouthfeel for sweetness, sourness, bitterness, mouthfeel, and aftertaste (duration), palatefulness, carbonation, and astringency. Finally, the panellists rated the quality of odour, quality of taste, and general quality. This ‘quality test’ was used for the overall beer quality. Sensory data was collected using Compusense Cloud Version 21.0.7773.19239.

Chemical analysis of volatile flavour compounds in beer

For a more comprehensive, quantitative assessment of volatile flavour compounds, the pilot scale beer samples were analysed at VLB (Berlin).

Higher alcohols (1-propanol, 2-methyl-1-propanol (isobutanol), 2-methyl-1-butanol, 3-methyl-1-butanol, 2-phenylethanol), acetate esters (ethyl acetate, isoamyl acetate, 2-phenylethyl acetate), and acetaldehyde were analysed using the Analytica EBC 9.39 method for analysis of lower boiling point volatile compounds in beer. Gas chromatography (GC) was performed on a Shimadzu GC-2010 with a flame ionisation detector and an AOC 5000 autosampler. An Agilent DB-Wax column (60 m x 0.32 mm x 0.5 µm, Agilent, Santa Clara, CA, USA) was used, with helium (Air Liquide) as the mobile phase. The GC oven program included temperature ramps from 40°C to 230°C. Data analysis was conducted using Shimadzu LabSolutions (version 5.87). The reference standards were from Sigma-Aldrich with a purity >98%. Aldehydes (2-methylpropanal, 2-methylbutanal, 3-methylbutanal, pentanal, hexanal, furfural, heptanal, methional, octanal, benzaldehyde, phenyl acetaldehyde, nonanal, trans-2-nonenal, decanal, and trans, trans-2,4-decadienal) were analysed by headspace solid phase microextraction (HS-SPME) gas chromatography tandem mass spectrometry (GC-MS/MS) (Dennenlöhr et al. 2020).

Fatty acid ethyl esters (ethyl butyrate, ethyl hexanoate, ethyl octanoate, ethyl decanoate, ethyl dodecanoate) were analysed via HS-SPME-GC-MS (Köhler et al. 2021), using a Shimadzu Nexis GC-2030 interfaced with a Shimadzu GC-MS QP2020 NX, with HS-SPME sampling using a Gerstel MPS Robotic XL. The GC contained a Restek Rtx-5MS column (30 m x 0.25 mm x 0.25 µm, Restek, Bellefonte, PA, USA) with helium (99.999%, Air Liquide) as the mobile phase. The GC-MS and extraction parameters were adopted from Schubert et al (2023). Esters were extracted from sample (2 mL) in a 10 mL head space vial with a DVB/CAR/PDMS fibre (Supelco). Internal standards d5-ethyl hexanoate and ^{13}C-ethyl octanoate were added to the sample as a mix, with rach at a final concentration of 100 µg/L. Data analysis was performed using LabSolutions, GCMS solutions version 4.50 SP1 (Shimadzu).

Statistical analysis

Data for fermentable sugars, ethanol, FAN, protein and polyphenol in laboratory scale wort and beer samples were examined with a one-way and two-way mixed model analysis of variance (ANOVA) as applicable, significant differences ($p < 0.05$). Tukey's HSD was used as the post hoc test.

Heat maps of the concentration of aroma compounds were generated in 'R' based on z-scores using the 'pheatmap' package. The z-scores (z) were calculated as $z = (x - \mu)/\sigma$, where x is the concentration of an aroma compound in a particular sample, μ is the mean concentration of the aroma compound in all samples, and σ is the standard deviation of concentration of that aroma compound in all samples. Principal component analysis (PCA) was performed using the 'prcomp' function in R.

Results and discussion

Wort and beers were prepared using different 'crop rotation' recipes at laboratory scale, with faba beans added in various forms. In addition to barley malt, wheat and oat malts were included to strengthen the regenerative agriculture aspect of the malt bill. The resulting wort and beers were analysed and compared for their physicochemical properties to assess whether using malted faba beans as a brewing adjunct offered an advantage. Based on these studies, raw faba beans, Sprau®, and starch fraction were selected for pilot scale trials.

Incorporating faba bean decreased wort fermentable sugar and the ethanol yield

To assess the effect of faba bean in its various forms on the fermentable sugar profile of wort and the alcohol content of the resulting beer, the samples were analysed using high-performance liquid chromatography (HPLC) Wort made solely from pale ale malt (Control 2) had the highest levels of fermentable sugars (maltotriose, maltose, glucose, and fructose), followed by the control containing crop rotation grains but not faba beans (Figure 1).

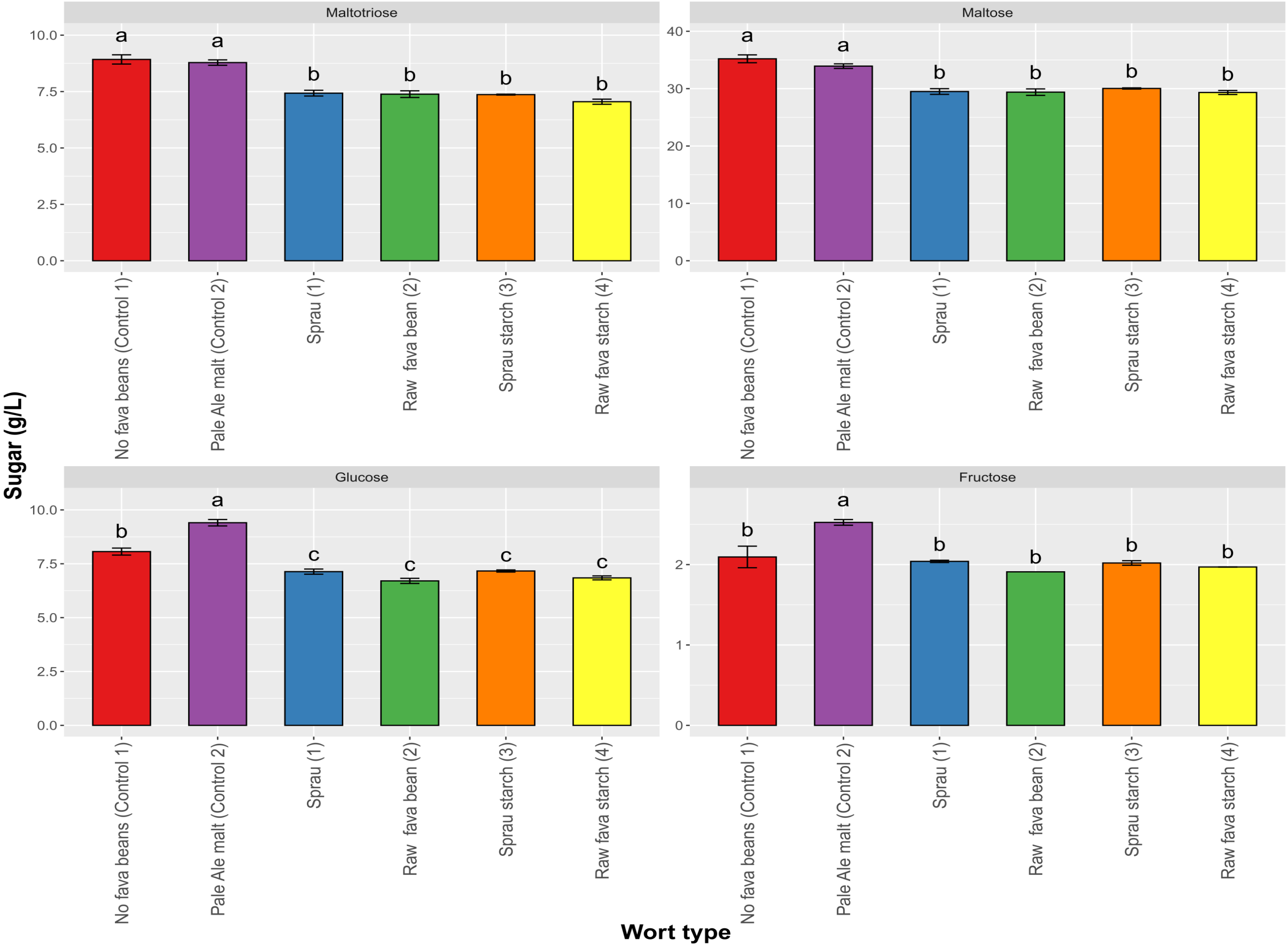
At a laboratory scale, wort containing faba bean had approximately 20% less of each fermentable sugar than the barley malt control, with no significant differences between the faba bean variants (Figure 1). A similar result was observed at pilot scale, with no differences in the sugar profiles of worts made with raw faba bean and Sprau® (Table 3).

The starch content of raw faba and Sprau® were not statistically different (Table 1). However, wort produced with Sprau® (Table 3) had a higher maltose concentration. This may reflect the lower pasting temperature of Sprau® compared to raw faba (Table 1), which may result in a minor improvement in starch solubility (Rittenauer et al. 2021). Post-fermentation analysis revealed a consistent but marginal increase in ethanol concentration in beers brewed with Sprau® faba bean and starch fraction compared to that brewed with raw faba bean (Figure 2, Table 3).

Figure 1.

Concentration (g/L) of maltotriose, maltose, fructose, and glucose in wort made at laboratory scale from faba bean: malted faba (Sprau®), raw faba, starch fraction of Sprau® and starch fraction of raw faba.

All values are the mean of two biological replicates (n = 2), with error bars indicating the standard deviation. Different letters indicate significant differences ($p < 0.05$) as determined by one-way ANOVA test and Tukey's post-hoc test.



Faba beans exhibit amylolytic activity during germination, which increases starch digestibility (Dhull et al. 2022). By adjusting the mashing temperature above the pasting temperature of malted faba beans (72°C), starch solubility can be further enhanced (Rittenauer et al. 2021; Deoghare et al. 2025). This, in turn, makes malted faba bean starch more susceptible to the action of barley enzymes during mashing, potentially boosting fermentable sugar levels in malted faba bean wort. However, only a modest increase in maltose was observed during pilot scale mashing of Sprau® containing crop rotation wort, despite mashing temperatures exceeding 72°C.

Nevertheless, this modest improvement in maltose concentration contributed to a marginal increase in ethanol concentrations. Because these beers contained only 42% enzyme active barley malt and 20% wheat malt, the overall amylolytic capacity of the mash may have been insufficient for complete saccharification of Sprau® starch. To overcome this, exogenous amylolytic enzymes could be added during mashing to improve starch breakdown and increase fermentable sugar concentration.

Incorporating Sprau® increases FAN and protein concentration while lowering polyphenol content

Faba beans and other pulses are rich in protein and incorporating them in the malt bill may be

Figure 2.

Levels of ethanol in beer made at laboratory scale from different forms of faba bean: malted faba (Sprau®), raw faba, starch fraction of Sprau® and starch fraction of raw faba.

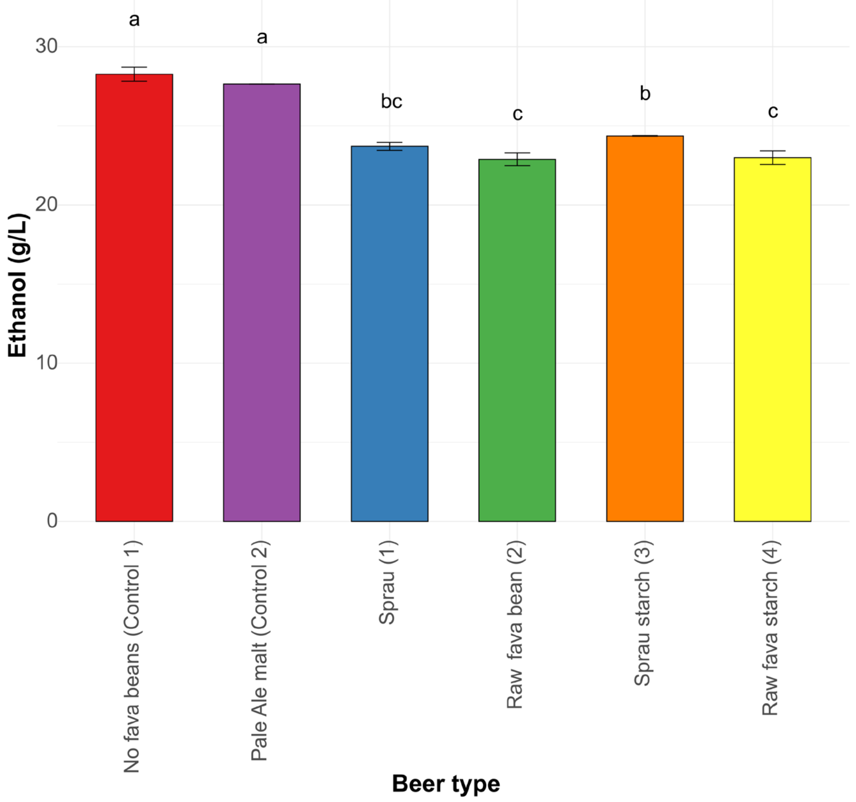


Table 3.

Physicochemical properties of pilot scale beers and worts.

Sample	Maltotriose	Maltose	Glucose	Fructose	Ethanol	Free Amino Nitrogen	Protein level > 3 KDa	Polyphenol
	g/L					mg/L		
P-1 wort	11.7 ± 0.22	42.5 ± 0.06	9.5 ± 0.07	3.4 ± 0.05	0	230.9 ± 5.5	331 ± 3	190 ± 5
P-2 wort	11.6 ± 0.31	41.9 ± 1.18	9 ± 0.3	3.3 ± 0.05	0	202.8 ± 0.3	273 ± 9	240 ± 2
P-3 wort	12.1 ± 0.07	41.7 ± 0.43	8.6 ± 0.09	3.2 ± 0.02	0	194.1 ± 0	324 ± 3	135 ± 2
P-1 beer	0.3 ± 0	0 ± 0	0 ± 0	0 ± 0	33.3 ± 0.8	125.7 ± 0	169 ± 3	167 ± 1.2
P-2 beer	0.5 ± 0	0.14 ± 0	0 ± 0	0 ± 0	32.8 ± 1.1	108.9 ± 10.8	131 ± 5	219 ± 1
P-3 beer	0.2 ± 0	0 ± 0	0 ± 0	0 ± 0	32.4 ± 0.4	104.5 ± 0	159 ± 3	125 ± 0

be anticipated to increase the free amino nitrogen (FAN) profile of the wort, potentially impacting on yeast growth, metabolism, and beer flavour.

At a laboratory scale, the pale ale wort (Control 2) had the highest FAN concentration at 204 mg/L (Figure 3) . Supplementation of the crop rotation wort with Sprau® (malted faba bean) increased the FAN concentration to levels comparable to Control 2. Conversely, adding Sprau® starch, resulted in FAN levels similar to Control 1. Although, the addition of raw faba resulted in FAN concentrations below those of Control 1, all worts prepared from faba at laboratory scale had FAN levels above 100 mg/L (Figure 3). At pilot scale, similar trends were observed, however, FAN concentration was generally higher than at laboratory scale (Table 3). The concentration of FAN in beers reflected the levels in wort indicating similar utilisation (97 ± 7 mg/L) during fermentation (Figure 3, Table 3).

FAN is useful for predicting yeast health, viability, fermentation efficiency, together with the quality and stability of beer (Stewart et al. 2013). A level of 100-140 mg FAN/L is recommended to for satisfactory yeast growth and fermentation performance in normal gravity (10–12°P) wort with 200-250 mg FAN/L is for high gravity (15-17°P) wort

(Hill and Stewart 2019). The increase in FAN level by the addition of Sprau® reflects the malting process and the activation of endogenous enzymes in faba beans, resulting in an increased concentration of amino acids and other nitrogenous compounds (Dhull et al. 2022). Indeed, malting can result in a 40% increase in folate during faba bean germination, which is a co-factor in amino acid synthesis and may contribute to the elevated FAN levels in Sprau worts (Dhull et al. 2022). Sprau® starch, with 40.9% more starch compared to Sprau®, contains comparably less protein (Table 1) with a more modest effect on FAN than whole Sprau®.

The amino acid profile of FAN influences the nitrogen metabolism of yeast and the formation of flavour compounds in beer (Ferreira and Guido 2018; Akkad et al. 2021). While raw faba beans provide high levels of lysine, leucine, isoleucine, threonine, histidine, and aromatic amino acids, they are lower in methionine, cysteine, and tryptophan (Martineau-Côté et al. 2022). Moreover, environmental conditions during cultivation and processing (e.g. malting), can alter the amino acid profile, affecting FAN quality and, consequently, beer flavour (Martineau-Côté et al. 2022). Although the addition of malted faba (Sprau®) to crop rotation grain worts increased FAN to levels of the barley malt control, the amino acid composition must be taken into consideration to optimise fermentation and beer flavour.

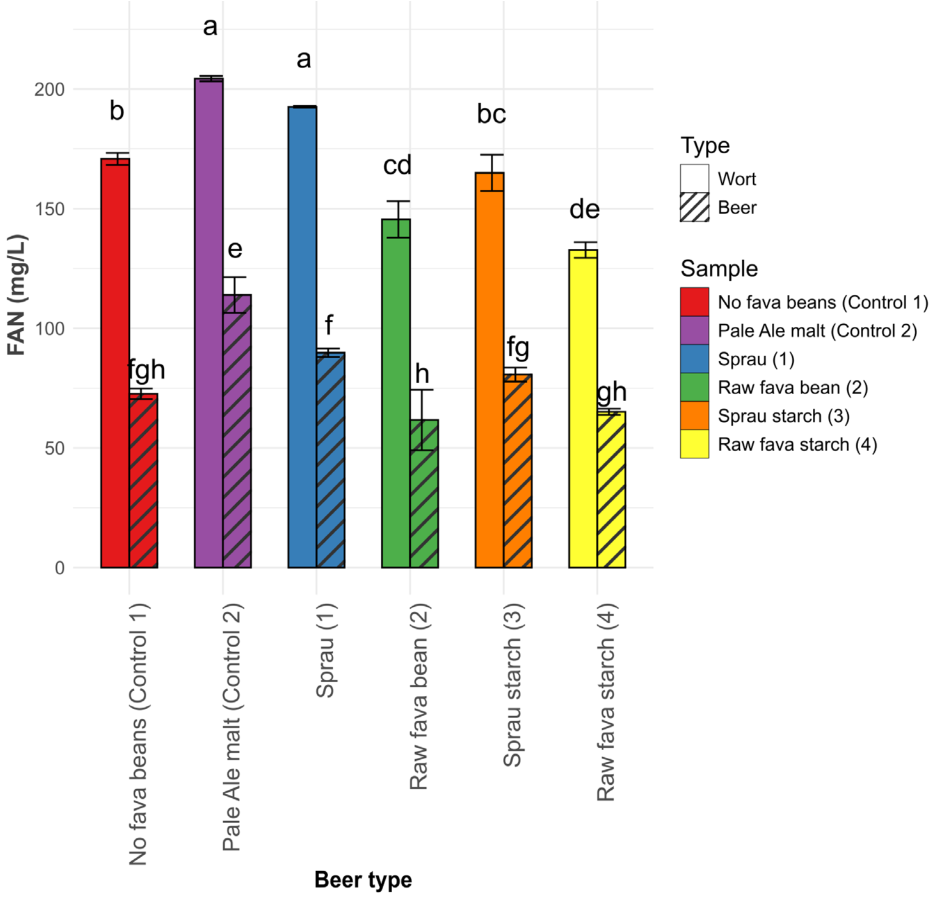
The impact on the colloidal stability of beer from crop rotation grain wort supplemented with faba beans was determined from the analysis of high molecular weight (> 3kDa) protein in wort and beer samples using the Bradford assay. In laboratory scale studies, supplementation with Sprau® or raw faba bean resulted in increased protein concentration compared to the crop rotation grain wort (Control 1) and malted barley wort (Control 2) which both had similar protein concentration (Figure 4). Worts from Sprau® malt or Sprau® starch fraction had the highest protein concentration (Figure 4), with both having a higher protein content compared to raw faba starch flour (Table 1). Notably, the protein concentration decreased in the beers (Figure 4), to similar levels across the samples, probably a result of protein precipitation during wort boiling. A similar trend was also observed in the pilot scale studies (Table 3).

Raw faba beans contain 26% protein and are a good source of lysine rich protein (Akkad et al. 2021;

Figure 3.

Free amino nitrogen (FAN) concentration in laboratory scale wort and beer made from different forms of faba bean: malted faba (Sprau), raw faba, starch fraction of Sprau® and starch fraction of raw faba in mg/L.

All values are the mean of two biological replicates (n = 2), with error bars indicating the standard deviation between them. Different letters indicate significant differences ($p < 0.05$) as determined by two-way ANOVA test and Tukey's post-hoc test.



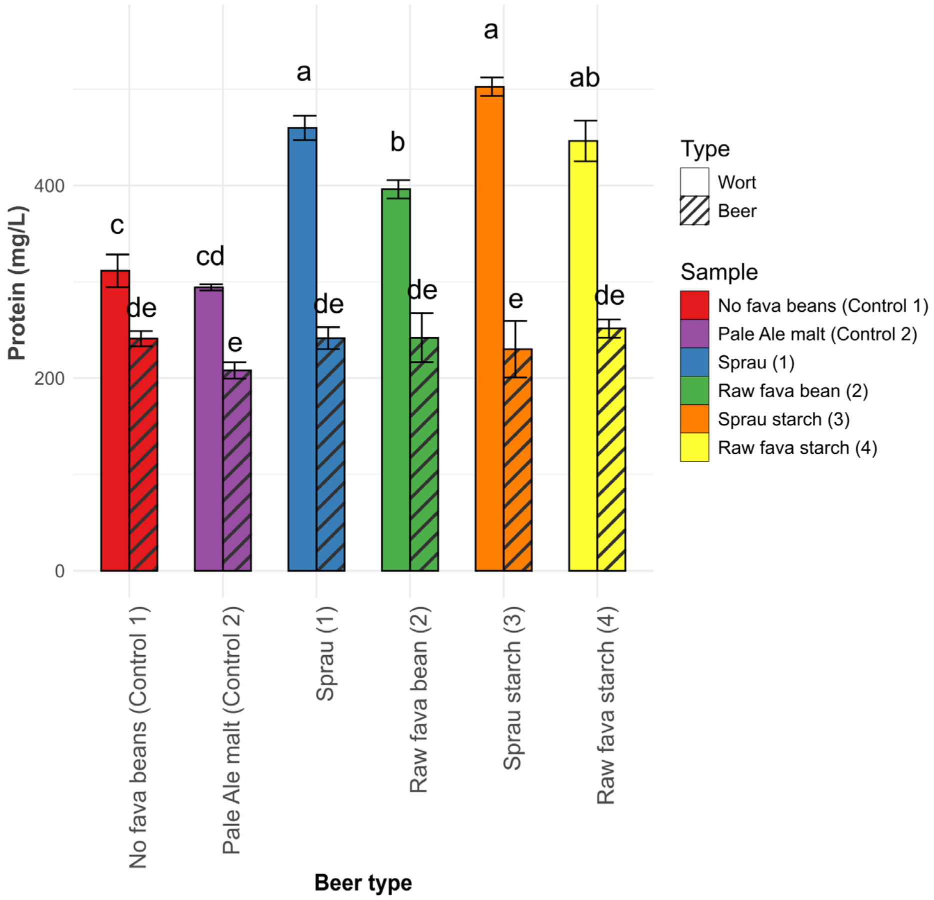


Figure 4.

Bradford protein concentration > 3kDa in laboratory scale wort and beer samples made from different forms of faba bean: malted faba (Sprau®), raw faba, starch fraction of Sprau® and starch fraction of raw faba measured in mg/L.

All values represent means of two biological replicates (n = 2), with error bars indicating the standard deviation between them. Different letters indicate significant differences ($p < 0.05$) as determined by two-way ANOVA test and Tukey's post-hoc test.

Black et al. 2021a). Akkad et al (2021) reported that sprouting faba beans enhance flavour quality and led to a 1.5% increase in protein content and protein digestibility over 72 hours. Supplementing the crop rotation wort with faba bean, particularly Sprau® increased protein concentration indicating enhanced nutritional potential. However, the protein content in the pilot scale beer brewed with Sprau® remained below the 500 mg protein/L found in commercial beers using the Bradford assay (Blasco et al. 2011; Niu et al. 2018). This may suggest a balance between nutritional enrichment and colloidal stability. This is essential, as sufficient protein is required for foam stability while avoiding an excess that could result in haze formation and reduce the shelf life of beer (Blasco et al. 2011; Devolli et al. 2018). Whilst the findings reported here, demonstrate the use of faba beans in brewing to improve nutritional profiles, optimisation will be necessary to maintain quality and stability of the final product.

Polyphenols offer antioxidant benefits and enhance beer foam, oxidative stability, flavour, and heat stability, but also can contribute to haze (Aron et al. 2010). Accordingly, polyphenol was measured to evaluate how various faba bean formats influence flavour, astringency, and haze in crop rotation grain beer. Results at laboratory scale showed higher levels of polyphenols in raw whole bean faba wort compared to wort made with Sprau® (malted faba) whole bean or starch. The lowest levels were found in the crop rotation grain wort (Control 2) and malted barley control (Control 1) (Figure 5). A similar trend was found in pilot scale beers (Table 3). In this study, Sprau® produced levels within the range (50-150 mg/L) for lagers (Aron et al. 2010). The results agree with Deoghare et al 2025, who found lower polyphenol levels in malted faba wort than in raw faba wort. However, hop addition at pilot scale increased polyphenol content, elevating the risk of haze and contributing bitterness, astringency, and unpleasant mouthfeel (Aron et al. 2010). Although malting effectively reduces polyphenols, control measures such as hexamethylenetetramine (HMT) or polyvinylpyrrolidone (PVPP), can mitigate excess polyphenols and optimise clarity (Aron et al. 2010).

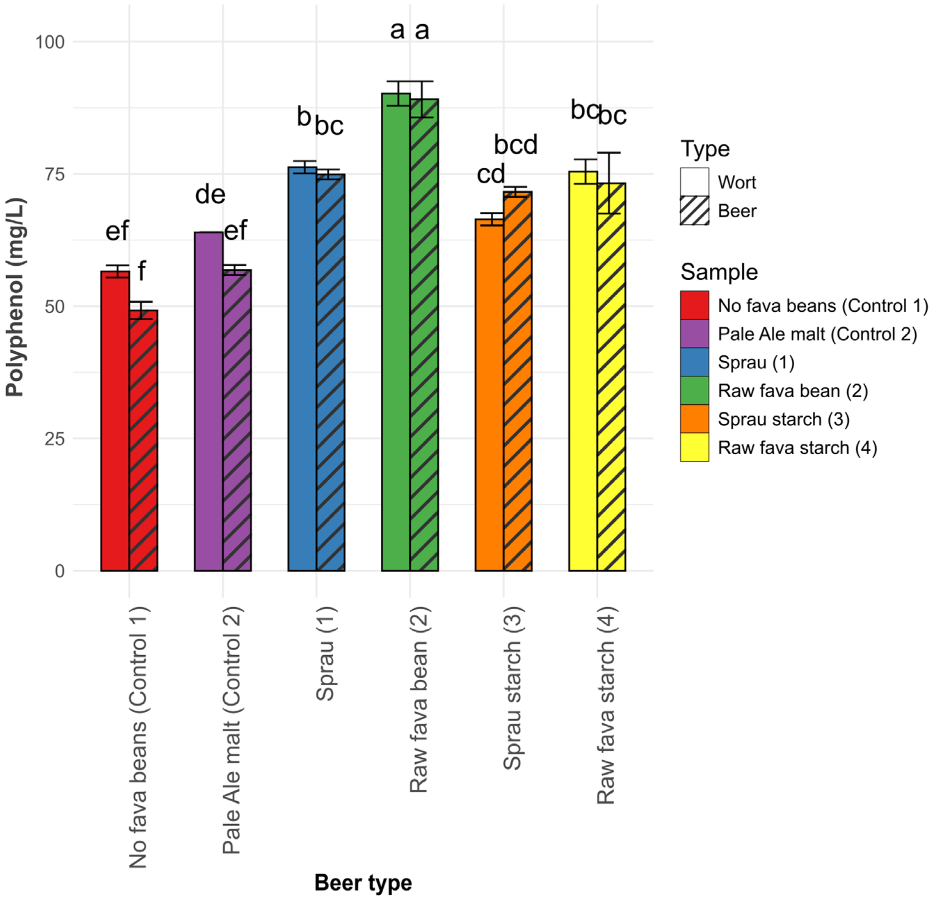
Brewing with Sprau® improves the sensory quality of crop rotation beers

To investigate the effect of Sprau® and raw faba bean (whole and starch) supplementation on the

Figure 5.

Polyphenol concentration (mg/L) in laboratory scale wort and beer samples made from different forms of faba bean: malted faba (Sprau®), raw faba, starch fraction of Sprau® and starch fraction of raw faba measured in mg/L.

All values represent means of two biological replicates (n = 2), with error bars indicating the standard deviation between them. Different letters indicate significant differences ($p < 0.05$) as determined by two-way ANOVA test and Tukey's post-hoc test.



aroma profile of laboratory wort and beer, volatile compounds were analysed using SPME-GC/MS. Of the different faba bean formats, supplementation of Sprau® resulted in aroma profiles of wort and beer that were comparable to those from pale ale malt (Figures 6 and 7). Wort samples were dominated by aldehydes, which were reduced during fermentation. The beer produced with Sprau® had similar levels of key esters - ethyl acetate, 3-methylbutyl acetate, ethyl hexanoate and ethyl octanoate - to that of the controls. These findings suggest that supplementation with Sprau® can be used in brewing without compromising the aromatic characteristics of the beer.

The three pilot scale crop rotation beers, brewed with Sprau®, Sprau® starch fraction, and raw faba beans were evaluated by a sensory panel of 10 trained tasters. The beers were also analysed using gas chromatography for quantitative detection of volatile compounds to further explore how malted faba beans influence the flavour profile. Beers containing Sprau® (P1) and its starch fraction (P3) demonstrated better odour, taste, and overall quality compared to the raw faba bean beer (P2) (Table 4).

The quality scores of the beers containing Sprau® were 'good' (>6) and on par with those from commercial malted barley. Beers P1 and P3 also showed more desirable sensory attributes, including improved balance, hop flavour, bitterness intensity, and ester fruity notes, while exhibiting less fatty character (Figure 8, Table 4). Furthermore, the beer made with Sprau® contained lower concentrations of off-flavour aldehydes than the raw faba bean beer reflecting the role of malting on the volatile composition of legumes. Additionally, flavour development during fermentation is linked to the level of free amino nitrogen (FAN) in the wort. FAN directly influences the formation of key flavour and aroma compounds such as aldehydes, esters, diacetyl, sulphur compounds, and higher alcohols (Hill and Stewart 2019). While insufficient FAN can limit ester production, excess FAN, and in particular branched chain amino acids, can result in off flavours such as diacetyl, elevated higher alcohols, and formation of Strecker aldehydes (Hill and Stewart 2019). Here, however, no clear links were observed between FAN and aroma active compounds.

Figure 6.

Heatmap of the relative concentrations of volatile aroma compounds in worts and beers (laboratory scale).

The heatmap is coloured based on Z-scores of the peak area for each compound in the wort samples (blue: negative Z-score, red: positive Z-scores). Data is presented as an average value of two biological replicates (n=2).

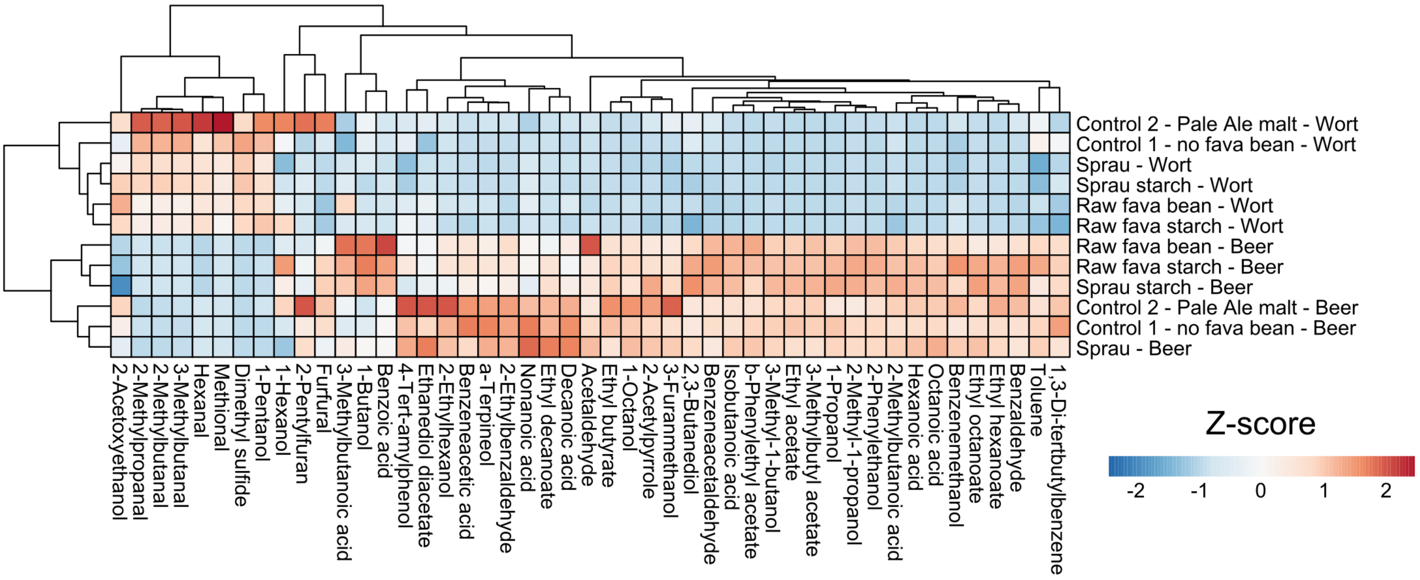


Figure 7.

Principal component analysis (PCA) of the relative concentrations of volatile aroma compounds in laboratory scale crop rotation beers supplemented with different forms of faba beans.

Data is an average value of two biological replicates (n=2). The plot to the left (A) shows sample scores, while the plot to the right (B) show compound loadings. PC1 and PC2 explain 77% of the variance.

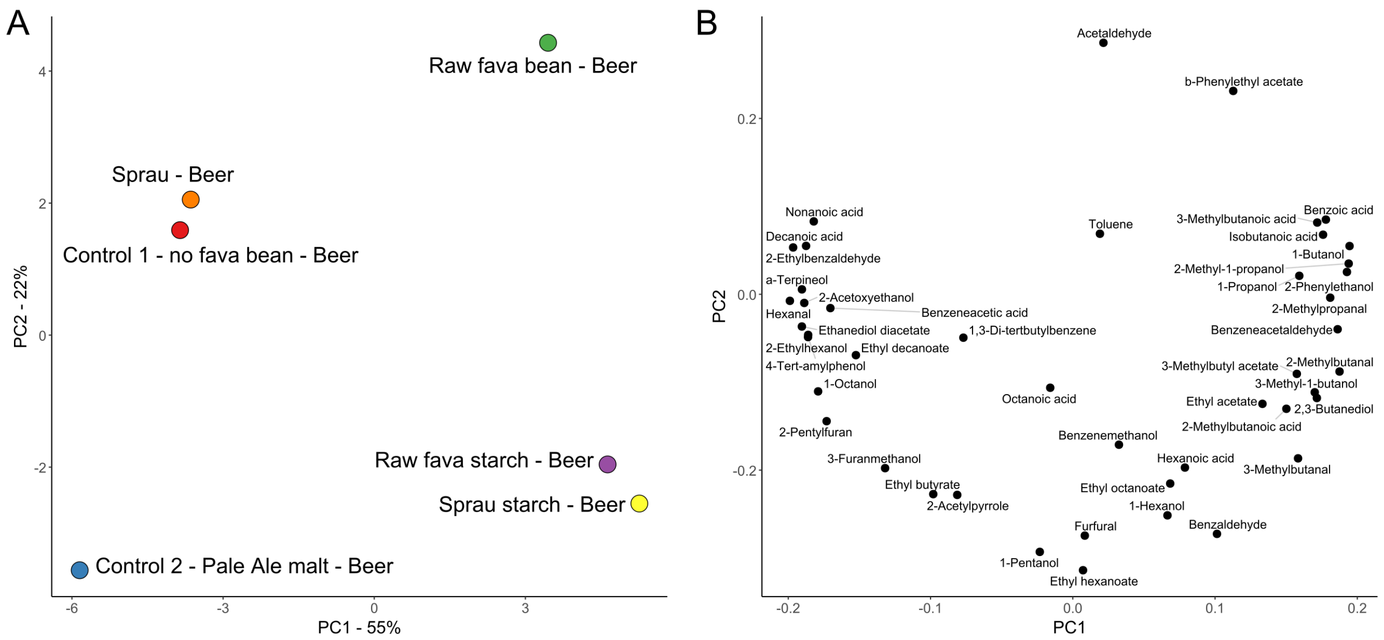
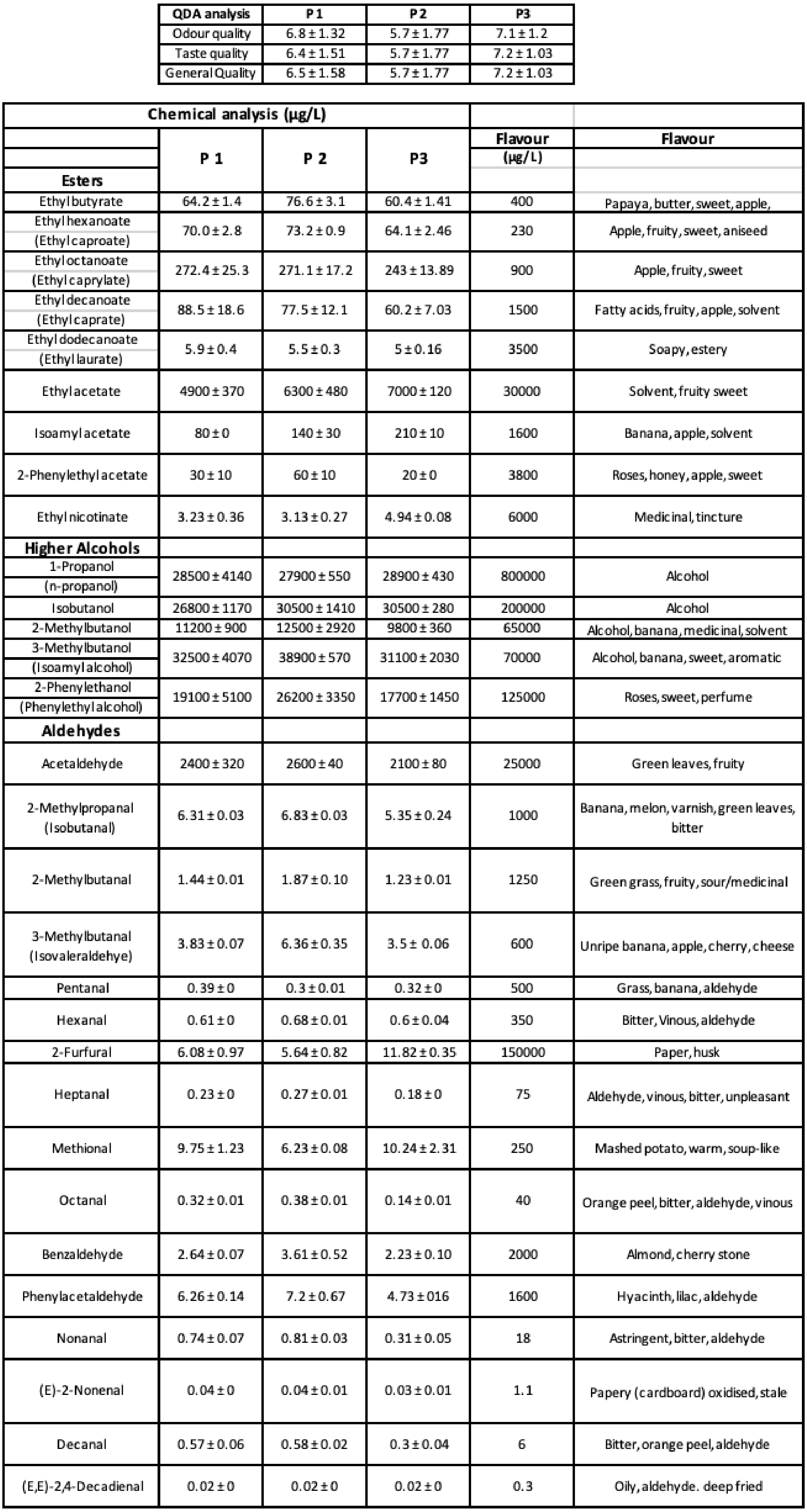


Table 4.

Qualitative Descriptive Analysis (QDA) and concentration of volatile compounds in the pilot scale crop rotation beers.

Data for flavour thresholds and descriptions in beer from Meilgaard (1975)



QDA analysis	P 1	P 2	P3
Odour quality	6.8 ± 1.32	5.7 ± 1.77	7.1 ± 1.2
Taste quality	6.4 ± 1.51	5.7 ± 1.77	7.2 ± 1.03
General Quality	6.5 ± 1.58	5.7 ± 1.77	7.2 ± 1.03

Chemical analysis (µg/L)					
	P 1	P 2	P3	Flavour (µg/L)	Flavour
Esters					
Ethyl butyrate	64.2 ± 1.4	76.6 ± 3.1	60.4 ± 1.41	400	Papaya, butter, sweet, apple,
Ethyl hexanoate (Ethyl caproate)	70.0 ± 2.8	73.2 ± 0.9	64.1 ± 2.46	230	Apple, fruity, sweet, aniseed
Ethyl octanoate (Ethyl caprylate)	272.4 ± 25.3	271.1 ± 17.2	243 ± 13.89	900	Apple, fruity, sweet
Ethyl decanoate (Ethyl caprate)	88.5 ± 18.6	77.5 ± 12.1	60.2 ± 7.03	1500	Fatty acids, fruity, apple, solvent
Ethyl dodecanoate (Ethyl laurate)	5.9 ± 0.4	5.5 ± 0.3	5 ± 0.16	3500	Soapy, estery
Ethyl acetate	4900 ± 370	6300 ± 480	7000 ± 120	30000	Solvent, fruity sweet
Isoamyl acetate	80 ± 0	140 ± 30	210 ± 10	1600	Banana, apple, solvent
2-Phenylethyl acetate	30 ± 10	60 ± 10	20 ± 0	3800	Roses, honey, apple, sweet
Ethyl nicotinate	3.23 ± 0.36	3.13 ± 0.27	4.94 ± 0.08	6000	Medicinal, tincture
Higher Alcohols					
1-Propanol (n-propanol)	28500 ± 4140	27900 ± 550	28900 ± 430	800000	Alcohol
Isobutanol	26800 ± 1170	30500 ± 1410	30500 ± 280	200000	Alcohol
2-Methylbutanol	11200 ± 900	12500 ± 2920	9800 ± 360	65000	Alcohol, banana, medicinal, solvent
3-Methylbutanol (Isoamyl alcohol)	32500 ± 4070	38900 ± 570	31100 ± 2030	70000	Alcohol, banana, sweet, aromatic
2-Phenylethanol (Phenylethyl alcohol)	19100 ± 5100	26200 ± 3350	17700 ± 1450	125000	Roses, sweet, perfume
Aldehydes					
Acetaldehyde	2400 ± 320	2600 ± 40	2100 ± 80	25000	Green leaves, fruity
2-Methylpropanal (Isobutanal)	6.31 ± 0.03	6.83 ± 0.03	5.35 ± 0.24	1000	Banana, melon, varnish, green leaves, bitter
2-Methylbutanal	1.44 ± 0.01	1.87 ± 0.10	1.23 ± 0.01	1250	Green grass, fruity, sour/medicinal
3-Methylbutanal (Isovaleraldehye)	3.83 ± 0.07	6.36 ± 0.35	3.5 ± 0.06	600	Unripe banana, apple, cherry, cheese
Pentanal	0.39 ± 0	0.3 ± 0.01	0.32 ± 0	500	Grass, banana, aldehyde
Hexanal	0.61 ± 0	0.68 ± 0.01	0.6 ± 0.04	350	Bitter, Vinous, aldehyde
2-Furfural	6.08 ± 0.97	5.64 ± 0.82	11.82 ± 0.35	150000	Paper, husk
Heptanal	0.23 ± 0	0.27 ± 0.01	0.18 ± 0	75	Aldehyde, vinous, bitter, unpleasant
Methional	9.75 ± 1.23	6.23 ± 0.08	10.24 ± 2.31	250	Mashed potato, warm, soup-like
Octanal	0.32 ± 0.01	0.38 ± 0.01	0.14 ± 0.01	40	Orange peel, bitter, aldehyde, vinous
Benzaldehyde	2.64 ± 0.07	3.61 ± 0.52	2.23 ± 0.10	2000	Almond, cherry stone
Phenylacetaldehyde	6.26 ± 0.14	7.2 ± 0.67	4.73 ± 016	1600	Hyacinth, lilac, aldehyde
Nonanal	0.74 ± 0.07	0.81 ± 0.03	0.31 ± 0.05	18	Astringent, bitter, aldehyde
(E)-2-Nonenal	0.04 ± 0	0.04 ± 0.01	0.03 ± 0.01	1.1	Papery (cardboard) oxidised, stale
Decanal	0.57 ± 0.06	0.58 ± 0.02	0.3 ± 0.04	6	Bitter, orange peel, aldehyde
(E,E)-2,4-Decadienal	0.02 ± 0	0.02 ± 0	0.02 ± 0	0.3	Oily, aldehyde. deep fried

Figure 8.

Spider plot of the sensory analysis of three pilot scale crop rotation beers.

Beer samples: P1 beer with Sprau®, P2 beer with raw faba beans, P3 beer with Sprau® starch fraction.

Conclusions

Here, 'crop rotation' beer - utilising malt made from four different crops - can be produced with similar physicochemical and sensory properties to a barley malt beer. Incorporating legumes in the malt bill supports sustainable farming practices, enhances biodiversity, and reduces reliance on cereal grains such as barley. Compared to raw faba beans, malted faba beans (Sprau®) exhibit superior physicochemical, functional, and sensory properties. As a result, incorporating malted legumes like Sprau® can yield beers with improved mouthfeel and a balanced flavour profile. Together, this offers brewers new alternatives for improving the sustainability of their products.

Author contributions

Nazia Deoghare: Conceived the study, designed and performed experiments, wrote the manuscript.
Raimo Koljonen: Conceived the study, designed and performed experiments, edited the manuscript.
Nils Rettberg: Performed experiments, edited the manuscript.
Annika Wilhelmson: Conceived the study, designed the experiments, edited the manuscript.
Kristoffer Krogerus: Conceived the study, designed the experiments, edited the manuscript.

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Conflicts of interest

Raimo Koljonen and Annika Wilhelmson were employed by Viking Malt, Nils Rettberg by VLB Berlin and Kristoffer Krogerus by VTT Technical Research Centre of Finland. Viking Malt produce commercially the malted faba bean Sprau®. Viking Malt had no role in the analysis or interpretation of the data.

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