Understanding the bisphenol content of leather: A study of chemical type and processing method

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Understanding the bisphenol content of leather: A study of chemical type and processing method.

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Abstract

Bisphenol A (BPA) has been identified as an endocrine disruptor. The endocrine system covers multiple functions within the body through a series of feedback loops that help with the regulation of organs through the secretion of hormones. As such, any chemicals which are endocrine disrupting can have widespread impact within the body or the natural environment. Despite this, over 1,000,000 tonnes / annum of BPA are produced, imported, and used within the EU. Also of concern are related substances to BPA, in particular Bisphenol S (BPS) and Bisphenol F (BPF) which, while less evidence exists, have had endocrine disrupting properties identified in Zebra fish, rats, mice and humans.

Both BPS and BPF are often found in leather, BPS is the starting material from which sulphone replacements syntans are produced, BPF is a byproduct in the production of phenolic syntans. Due to the environmental concerns, the European Union is proposing restrictions in total bisphenol content in leather of 10 mg/kg, with a higher limit of 500 mg/kg between 2025 and 2030 making the presence of bisphenol compounds in leather a compliance as well as an environmental issue. Despite the proximity of these new regulations in the EU, there is little information in the public domain related to their presence in leather chemicals and their transference into leather and there is an urgent need for research in this regard.

Here we have applied high performance liquid chromatography (HPLC) to study bisphenol content in replacement syntans and their incorporation into leather. Significant variations in BPS and BPF content were observed. Sulphones contained between 207 and 41,200 mg/kg BPS, though most had concentrations above 6,000 mg/kg. Phenolic syntans contained between 240 and 563 mg/kg. Bisphenol contents were higher in belly areas compared with those measured at the official sampling position (OSP) by 12 – 14%, questioning the suitability of the OSP as a sampling position. A comparative trial of 4 separate approaches to leather processing was undertaken, it was demonstrated that final leather BPS and BPF concentration can vary depending on the point of application of the replacement syntan and other variations with up to 25 – 35% reduction of final leather bisphenol content achievable.

Keywords: Bisphenol, Restrictions, Syntans

1. **Introduction**

Bisphenol compounds are those that contain two phenolic groups, linked through a chemical bridge. The most common is bisphenol A (BPA) which had an estimated global production of 7.49 million tonnes in 2022.(1) BPA is formed through the condensation of two phenol compounds with acetone, producing the compound shown in **Figure 1.1**. Often incorrectly referred to as a plasticiser, this chemical is tyically present as an unreacted starting material in the production of polycarbonates, resins, other plastics and

certain papers.(2,3) Other common types of bisphenols include bisphenol F (BPF) and bisphenol S (BPS) which, while not produced at the scale of BPA, still feature significantly.(4) Their structures are also shown in **Figure 1.1** where BPF is produced from the condensation of phenol with formaldehyde and BPS is formed from the condensation of phenol with sulphonyl chloride.

In the case of leather manufacture, both BPF and BPS have the potential to be present in high concentrations. BPF is formed from the condensation of phenol with formaldehyde, the reaction which generates phenolic syntans, and BPS is the starting material from which sulphone syntans are produced.

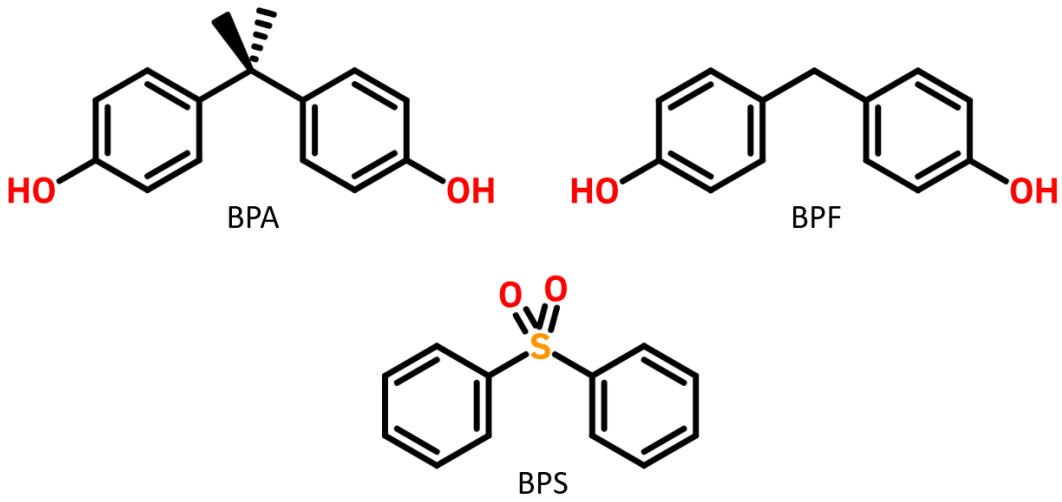


Figure 1.1: Chemical structures of bisphenol A (BPA), bisphenol F (bisphenol F) and bisphenol S (BPS).

Bisphenol A (BPA) has been identified as an endocrine disruptor.(5) The endocrine system covers multiple functions within the body through a series of feedback loops that help with the regulation of organs through the secretion of hormones. The potential of man-made compounds to interfere with the endocrine sytem has been identified since the early 90's (5) and since then has been extensively studied. BPA has moderate toxicity at 3520 mg / kg bodyweight for rats when consumed orally.(6) However, it is the endocrine disrupting properties that have recieved the most study, where it has been demonstrated that BPA is a xenoestrogen, mimicing the behaviour of estrogen-17-β-estrodiol. Although, the activitiy towards typical estrogen receptors was identified as 1000 – 10,000 times lower than 17-β-estrodiol, investigation has showed that even at very low concentrations (pico and nano-molar) influence on physiological function of cells and tissues can be observed.(6) In humans, Meeker et al showed that BPA concentration was inversely associated to male fertility.(7) In addition, there are suggested links between increased BPA concentration and obesity, diabetes, heart disease and other potential effects in the body.(6)

Also of concern are related substances to BPA, in particular Bisphenol S (BPS) and Bisphenol F (BPF) which, while less evidence exists, have had endocrine disrupting properties simmilar to BPA identified in Zebra fish, rats, mice and humans.(8) BPA, BPF and BPS have all been identified in both the influent and effluent of waste water treatment plants suggesting that these compounds are making their way into the environment (9) and both BPA and BPS have been identified in the urine of 95% and 81% in a study of multiethnic US adults. (10,11)

Due to these environmental concerns, the European Union is proposing restrictions on the total bisphenol content of leather at 10 mg/kg, with a higher limit of 500 mg/kg between 2025 and 2030, making the presence of bisphenols compounds in leather ca compliance and well as an environmental issue.(12)

Given their presence within leather, their impact on the environment, humans and animals and their potential restriction wthin the EU by 2025, the study of bisphenols has recently become an area of intense study within the leather community. At the FILK Freiberg Leather Days meeting 2023, there were five

separate presentations / Q&A sessions related to the topic of bisphenols from phenolic and sulphone syntans and the detection / minimisation in leather. Additionally, BS EN ISO 11936:2023, a standard for the detection and measurement of bisphenol compounds within leather was formally released in July 2023. While there has been much presentation of results at conferences, the authors could find no peer review academic publication related to the BPS and BPF content of leather. In addition, as much of the work has been undertaken by chemical companies that supply the leather sector, understandably the focus has been on the reduction of bisphenol content of leather through the reduction in the bisphenol content of the chemicals used in their manufacture.

This study focussed on the technical aspects of leather manufacture and how this relates to the bisphenol content of leather. Firstly, leather is an inhomogenous material and thus there is no expectation that the bisphenol conentration should be consistent across the surface of the leather. Secondly, how does the approach to processing influence the final leather bisphenol concentration. This study reports the outcomes of three trials studying the incorporation of BPS and BPF into leather. In the first two trials are range of chemicals that contain BPS (trial 1) and BPF (trial 2) are applied through a standard post-tanning process to evaluate the consistency in incorporation of bisphenol into leather and how this varies whether measurement is undertaken from the official sampling position (OSP), belly or the neck regions. The final trial uses a combination syntan that contains both BPF and BPS and studies the influence of processing methodology on the final bisphenol concentration of the leathers produced.

2. **Material and Methods**

4 wet-salted UK domestic bovine hides were procesed though to wet-blue condition and subsequently shaved to a thickness of 1.5/1.6 mm. Processing was undertaken in a pilot trial polypropylene drum equiped with a combination of shelves and pegs. The tanned hides were after being allowed to settle overnight, follwoed by dewatered through samm-setting.

Due to space limitations, the processes are not included here, however they can be found at the relevant entry on Assoc. Prof. Andrew Ballantyne's research profile at the following link: https://pure.northampton.ac.uk/en/persons/andrew-ballantyne/publications/

2.2 Design of post-tanning experiments

Each wet-blue hide was cut into 4, down the backbone of the hide and from belly to belly through the centre of the official sampling position (OSP), 1/3 of the distance from 'Butt' to the 'Neck' of the hide. Each quarter hide was assigned a position LB (left-hand-side butt), LN (left-hand-side neck), RB (right-hand-side neck) and RN (right-hand-side neck) which formed the basis of one trial. To ensure consistency and reliability of results each trial used quarters that originated from the same hide . Depending on the study, samples were taken from the OSP, belly area and neck area (where possible). Samples were taken from the crust leather, and in some cases the intermediate stages of leather preparation. These were the neutralisation bath (Neut), the retanning bath (Retan), and the fatliquor bath after fixation (Fat). Those samples which were not tanken from crust leather were dewaterred using a rudimentary mangle to ensure as simmilar dewattering as feasible to the 'samm-setting' process used for the crust leathers.

Three trials were undertaken in total, as outlined in **Table 2.1**, to study the transference of bisphenols from chemicals which contain them, into the leather. For trials 1 and 2, the bisphenol content of a range of replacement syntan chemicals were measured. From this Syntan A, B, C, D were selectrod for use in trial 1 and syntan E, F and G were selected for use in trial 2.

Table 2.1: List of four trials incorporated into this paper.

Trial number	Study
1	BPS content of leather from different BPS containing chemicals Syntan A, Syntan B, Syntan C, Syntan D.
2	BPF content of leather from different BPF containing chemicals Syntan E, Syntan F, Syntan G.
3	Influence of 4 different approaches to leather processes on BPS and BPF content of leather Syntan E

Table 2.2: 'Standard' processing of 1.6 mm bovine wet-blue to crust leather

Process	%	Chemical	Temp (°C)	Run
Wet-back	250	Water	40	10
Drain				
Neutralisation	100	Water	40	
	2	Sodium formate		15
	0.5	Sodium bicarbonate		60
Drain				
Wash	200	Water	40	10
Drain				
Retanning	100	Water	40	
	3	Acrylic syntan		20
	6	Replacement syntan		60
Drain				
Fatliquoring	100	Water	60	
	4	Sulphated fatliquor		
	2	Sulphited fatliquor		
	1	Emulsifiable fatliquor		60
	1	Formic acid (dil1:10)		40
Drain				

Process	%	Chemical	Temp (°C)	Run
Wash	100	Water	25	
Drain				
Horse up				
Samm sett / vacuum dry / hang dry / stake				

Each of the syntans of study in trial 1 and 2 were applied through a standardized process as outlined in **Table 2.2**. Neutralisation pH was in the range from 4.9 to 5.1. Final leather pH was between 3.5 and 3.7. The replacement syntans were as specified in **Table 2.1**. Where a liquid syntan was used, 12%, relative to the mass of wet-blue was applied. Fatliquors were stirred together and diluted 1:4 with 50 °C water.

Trial 3 studied the effect of changes in processing. Syntan E was chosen as it contained both BPS and BPF enabling direct comparison between each bisphenols in the one trial. The four variations are described in **Table 2.3** as modifications of the 'standard' process described in **Table 2.2**.

Table 2.3: List of four processing variations incorporated into trials 3 and 4

Variation	Description
Neut	Replacement syntan added into neutralisation bath at the end of the neutralisation process, instead of during 'retanning'.
STD	The 'standard process' as outlined in **Table 2.2**.
R-Fix	Additional fixation step added at the end of retanning. 0.5% formic acid diluted 1:10 with water added for 20 mins.
1 - Bath	'Retanning' and 'Fatliquoring' undertaken in same bath. No drain after retanning and no additional water added prior to addition of fatliquor.

2.3 HPLC Sample preparation

2.3.1 Preparation of syntan samples for measurement of bisphenol concentration

50 mg of syntan was added to a weighing bottle, to which was added 10 ml of methanol. This solution was added to a sonic bath at room temperature for 30 mins. The extractant was filtered, and the filtrate added to a 2 ml glass HPLC bottle for measurement. Each filtered sample was measured in duplicate.

2.3.2 Preparation of leather samples for measurement of bisphenol concentrations.

Crust samples were taken from the OSP, Belly and Neck (where possible) positions and placed in a conditioned room at 23 °C and 55% relative humidity for at least 48 hours. OSP samples taken during leather processing were passed through a mangle to reduce moisture content and dried naturally in the air. Once dry, samples were placed in a conditioned room at 23 °C and 55% relative humidity for at least 48 hours.

0.49 – 0.51 g sample was measured to the nearest 1 mg, cut into small pieces and placed into a sample tube with 10 ml methanol. The leather samples in methanol were sonicated in a water bath at 60 °C for 60 mins. Subsequently, the sample tube was removed and allowed to cool. The extractant was filtered and transferred to a 2 ml glass HPLC bottle for measurement. Duplicate extraction measurements were obtained from separate pieces of leather.

2.4 HPLC measurement

2.4.1 Equipment specifications and chemicals

Chromatograms and UV-vis spectra were recorded using a Thermo Fisher Scientific Ultimate 3000 HPLC equipped with LPG-3400SD gradient pump, WPS-3000SL autosampler, TCC-3000SD column compartment. and DAD-3000 UV-visible detector array. The column compartment contained a reverse-phase C18 column, 100 mm* 2.1 mm*2.7 µm. Tubing was 0.18 mm 316 stainless steel. The wash solvent was 10% methanol in Ultrapure water.

2.4.2 Procedure

Elution solvents were ultrapure water and acetonitrile, both of which contained 0.1% w/v trifluoroacetic acid. Injection volume was 5 µl, column temperature 40 °C and flow rate of 400 µl/min. The injections were subjected to a gradient flow program specified in **Table 2.4**.

Table 2.4: Solvent gradient program for elution of extracted chemical and leather samples for detection of BPA, BPB, BPS and BPF.

Time (min)	Ultrapure water (%)	Acetonitrile (%)
0	95	5
4	80	20
6	80	20
8	50	50
9	5	95
11	5	95
11.5	95	5
20	95	5

2.4.3 Calibration and detection

The elution response of BPA, BPF and BPS was evaluated and calibrated. The detector was set to record at both 230 nm and 253 nm wavelength. BPA and BPF were calibrated from the peak areas at 230 nm. BPS was calibrated and measured from the peak area at 253 nm. Calibration was undertaken at a range of concentrations between 0.5 and 10 mmol l^{-1} with calibration factors obtained through best linear fit of concentration against peak area. This data can be found in **Table 2.5**.

2.4.4 Determination of concentration

Respective bisphenol concentration of chemical and leather samples was calculated according to equation 1. w is the mass fraction, expressed in mg/kg, A_s is the peak area from the chromatograph, V is the final volume used in the extraction (0.01 l), a is the slope of the calibration graph and m is mass of extracted chemical or leather sample in g.

$w = \frac{A_{s}V}{a.m}$ Equation 1

Table 2.5: Detector wavelength, calibration factor and elution time for standardised bisphenol solutions.

Bisphenol	Detection wavelength (λ) (nm)	Peak area to solution concentration calibration (mAu.ppm/min)	Elution time (mins)
BPA	230	0.485	10.5 – 10.8
BPF	230	0.8923	8.6 – 9.8
BPS	253	0.977	5.8 – 6.0

3. **Results and Discussion**

3.1 Concentration of bisphenol F and S in replacement syntans

Initially, the bisphenol content of a series of replacement syntans chemicals were measured, which were chosen at random from those available within the facilities at ICLT. The chemicals were from a variety of companies that supply the leather sector and supplied before any notice regarding potential restrictions was publicized. A combination of chemicals was chosen whose technical data sheets described these chemicals as ‘sulphone condensation products’, ‘phenolic condensation products’ or a combination of ‘sulphone and phenolic condensation products’, which have been provided the labels ‘sulphone’, ‘phenolic’, and ‘combination’ in **Table 3.1**. The bisphenol content was tested in a modified method from that described in BS EN ISO 11936:2023, where modification was made due to the extraction of the chemical, as opposed to the leather itself.

Table 3.1. BPF and BPS content of replacement syntan chemicals A – G and resulting concentration in leather when applied through the standard process outlined in Table 2.4.

Syntan		Chemical bisphenol conc. (mg/kg)		Trial	Leather sample area	Leather bisphenol conc. (mg/kg)	
Type	Syntan	BPF	BPS			BPF	BPS
Sulphone	A	-	23954 ± 185	1	OSP	-	1334 ± 17
					Belly	-	1508 ± 75
Combi	B	452 ± 1	11000 ± 87	1	OSP	14.8 ± 0.1	548 ± 3
					Belly	16.1 ± 0.4	576 ± 15
					Neck	15.5 ± 0.5	555 ± 2
-	C	-	41212 ± 50	1	OSP	9.5 ± 0.6	1871 ± 86
					Neck	10.8 ± 0.2	1970 ±37
Sulphone (liquid)	D	-	33352 ± 20	1	OSP	20.2 ± 0.1	3571 ±13
					Belly	31.0 ± 1.2	4026 ± 16
					Neck	34.2 ± 0.5	3985 ± 113
Combi	E	378.3 ± 20.9	6921 ± 17	2	OSP	66.9 ± 0.7	240 ± 1
					Belly	75.3 ± 0.3	263 ± 0.5

Syntan		Chemical bisphenol conc. (mg/kg)		Trial	Leather sample area	Leather bisphenol conc. (mg/kg)	
Type	Syntan	BPF	BPS			BPF	BPS
Phenolic	F	246.8 ± 3.6	-	2	OSP	15.6 ± 0.1	12.5 ± 0.1
					Belly	17.6 ±0.1	19.4 ± 0.5
					Neck	17.2 ±0.1	11.1 ± 0.1
Phenolic (liquid)	G	563.8 ±10.1	58.9 ± 1.1	2	OSP	84.6 ± 0.8	20.6 ± 0.8
					Belly	94.3 ±0.3	26.2 ± 0.3
					Neck	90.88 ± 0.9	19.1 ± 0.7

The levels of both BPS and BPF varied substantially between the chemicals of study. Those where only BPS was identified possessed the higher overall bisphenol content, up to a value of 66,000 mg / kg for chemical D. This value, while being high in respect of prospective EU regulations, still only represents 6.6% of residual monomer, demonstrating the challenge of ensuring that sufficient monomer of BPS is consumed during chemical product manufacture. For chemicals F and G in **Table 3.1**, BPF was identified as either the dominant or sole bisphenol present within the chemical. The BPF levels in this case were substantially lower than that observed for BPS containing chemicals, with BPF concentrations of 246.8 and 563.8 mg / kg for chemicals F and G respectively. The third class of chemicals, labelled ‘combination’, contained substantially lower BPS concentrations than those that only had BPS identified of 11,000 and 6921 mg / kg for chemicals B and E respectively.

Direct measurement of individual bisphenol compounds showed excellent sensitivity to below 0.1 mg/l in each case. However, measurement was more challenging when considering the replacement syntan chemicals. It is necessary to consider that these measurements are on extractants of products which may contain a variety of components and as such there is the capacity that some co-extractants interfere with the measurements. In the case of BPS, interference from co-extractants was rare and BPS concentration values were high, meaning that for an interfering co-extractant, concentration would also need to be high to interfere. However, in the case of BPF the measured values were lower, and, in some cases, interfering peaks were also observed on the HPLC traces meaning that measurement confidence was lower.

3.2 Concentration of BPS and BPF in leathers produced using chemicals A – G.

Each of the chemical’s A – G used in a standard post-tanning process using 1.5 – 1.6 mm wet-blue hides, produced *in house* from wet-salted state within the facilities at ICLT. Processing to wet-blue avoided the use of unnecessary chemicals which had potential to interfere with bisphenol measurement. Thus, no chrome syntan, dispersing agent or fatliquors were used in the wet-blue preparation from deliming onwards. A non-ionic universal degreasing and wetting agent was used in the soaking and unhairing / liming process.

Two trials were undertaken, with trial 1 studying the incorporation of BPS from four syntans and trial 2 studying the incorporation of BPF from three syntans into leather. Each trial was on 1 hide, cut into quarters down the backbone and from belly to belly cut through the official sampling position. After processing, samples were cut from the OSP, belly area and, where available, the neck regions. Each quarter was then processed independently in identical drums according to the ‘standard’ post-tanning process described in **Table 2.2.** Given the inhomogeneity of collagen structure, it is important to understand if, and how, bisphenol concentration changes across different parts of the hide.

The BPS content for crust samples of leathers produced from BPS containing syntans A – D are shown in **Table 3.1** and **Figure 3.1 a)**. Calculated from the OSP sample, the BPS content is approximately 1/20th the concentration that was observed in the chemical product that was applied, varying from 1/18th to 1/22nd the concentration for syntans B and D respectively. This shows a reasonable consistency in BPS concentration in leather, relative to that measured in the chemical product. **Figure 3.2 b)** presents the BPF content for crust samples from syntans E, F and G. There is a larger discrepancy between the chemical and leather BPF concentrations. This is likely to be due to the presence of interferents in the chemical HPLC traces. Intuitively, as a unique product it may be expected that fewer interferents would be present from measurements of the chemical. However, the opposite was observed, where fewer interferents were observed on the leather HPLC traces compared, meaning the values measured on leather can be stated with greater confidence than the values of the leather, but it is inappropriate to compare the BPF concentration of the chemical with that of the leather.

Most interestingly, the OSP consistently measures the lowest BPS concentration relative to samples taken from other areas of the hides. When considering different areas of the hide, in all cases, the OSP had the lowest values for both the BPS and BPF concentration. This is shown in Table 3.2, where samples measured from the belly region had c.a. 10% higher concentration for both BPS and BPF. The belly area of the hide possesses the most open structure of collage fibers, followed by the neck area, with the OSP possessing the densest fiber structure. This open nature of the fibers in the belly region may aid the penetration of the bisphenol compounds deeper in the fiber structure, making them more persistent in the subsequent fatliquoring and washing stages.

Table 3.2 Average % increase of BPS and BPF concentration on crust leather relative to the official sampling position (OSP).

Sample position	**BPS (% relative to OSP)**	**BPF (%relative to OSP)**
OSP	100	100
Belly	110.5 ± 6.6	112.3 ± 0.7
Neck	106.4 ± 7.2	108.8 ± 2.0
a)		
b)		

Figure 3.1 a) BPS content of leathers produced from syntans A – D and **b)** BPF content of leathers produced from syntans E – G. These are graphical representations of the values provided in the final two columns in **Table 3.1**.

3.3 Influence of processing parameters on leather concentration of bisphenol F and S

Trial 1 and **2** studied the incorporation of BPS and BPF into leather through a standard process. However, there is little knowledge regarding how the approach to processing may impact on the final BPS and BPF concentration of leather. **Trial 3** aimed to increase knowledge in this regard through the application of Syntan E to the four separate processes outlined in **Table 2.3**, where each of the variations represent common approach to leather manufacture and the application of syntans. The process **STD** is outlined in **Table 2.2**, the process **Neut** applies the syntan at the end of the neutralization process in the neutralization bath, process **R- Fix** possesses an additional fixation step after application of the replacement syntan and **1-Bath** undertakes the retanning and fixing process in the same bath, with no draining of the float between the two processes.

As Syntan E contained both BPS and BPF, use of this syntan represents an excellent opportunity to observe how leather crust bisphenol concentration varies depending on approach to processing. The final crust bisphenol concentrations are shown in **Figure 3.2 a)** for BPS and **b)** for BPF for the four leathers produced. For both BPS and BPF, processing can have a significant demonstrable impact on the final bisphenol concentrations. The observations were in the order anticipated. Neut has the syntan added at an earlier stage with resulting leather passing through an increased number of baths before drying and so it was anticipated that the concentration would be lower. R-Fix applies acid to reduce leather pH at the end of the retanning process, increasing the substrate affinity for phenolic compounds, of which both BPS and BPF are classified, and is consistent with an increase in bisphenol concentration of the leather. The 1-bath process has the highest concentration for both BPS and BPF, again consistent with the expectations, given that there are reduced opportunities for dilution of the float and removal of bisphenol from the protein fiber structure.

a)	b)

Figure 3.2. a) BPS and **b)** BPF content of crust leathers produced from four different post-tanning approaches, each utilizing combination syntan E, as outlined in **Table 2.3**.

As described, the observation trends are in line with rational expectations when considering the different processes. However, the size of the difference in concentration depending on approach is striking. This is highlighted in **Table 3.3**, where a 38% difference in BPS and 39.5% difference in BPF concentration relative to the STD was observed between the Neut and 1-Bath processes.

Table 3.3. Average % variation of BPS and BPF concentration on crust leather relative to STD process in trial 3 studying different approaches to the application of syntan E.

Process	% conc. BPS relative to STD	% conc. BPF relative to STD
Neut	82.6	77.5
STD	100.0	100.0
R-Fix	112.6	114.2
1-Bath	119.8	117.0

While these results demonstrate that it is possible to reduce final leather bisphenol concentration through adjustment to the post-tanning approach, these are often contrary to current sustainable practice. Modern leather producers seek to reduce their environmental footprint by reducing resource consumption, reducing pollutant concentration in tannery effluents, and minimizing water consumption. These approaches are exemplified in the R-Fix and 1-Bath processes, yet they also contain the highest bisphenol concentration. However, the Neut process, where the replacement syntan was added into the neutralization bath, prior to the typical retanning step, produced leathers with the lowest bisphenol concentration. In this case, both modern sustainable practice and reduction in leather bisphenol content are in alignment.

The variations in BPS and BPF content during **Trial 3** have been measured at various intermediate stages of processing, as shown in **Figure 3.3**. The Neut process was exposed to repeated fresh floats as the process proceeds that result in multiple opportunities for the bisphenol compounds to be extracted during the natural leather making process, resulting in a low final leather content. A similar trend is observed in the STD process, although the final crust has a higher bisphenol content, likely due to the exposure to one fewer float.

a)
b)

Figure 3.3. a) BPS and **b)** BPF content of samples taken at various stages of processing from four different post-tanning approaches, as outlined in **Table 2.3.**

4. **Conclusion**

Investigations into the bisphenol content of chemicals and their resulting leather offers significant value given their potential environmental and health impacts, along with impending regulations. To our knowledge, this represents the first study of the technical aspects of leather manufacture on the concentrations of BPF and BPS and represent a significant contribution knowledge. Two key observations were observed that we have not seen observed before. First, the concentration of BPF and BPS can vary by up to 12%, depending on the location from which the sample is taken. Secondly, the approach to post-tanning can have substantial impact on final leather bisphenol concentration, although often approaches that lower bisphenol concentration also have a higher water consumption and pollution load of effluents. However, through the addition of the replacement syntan at an earlier stage, such as in the neutralization bath, it is possible to reduce leather bisphenol concentration without negatively influencing the other process efficiency aims.

5. **Acknowledgements**

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