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Bridging traditional and scientific knowledge on reindeer meat smoking - a pilot study

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ABSTRACT
Smoking reindeer meat in a traditional Sámi *lávvu* (tent) is a knowledgeable and long tradition for food preservation among Sámi reindeer herders. However, due to the formation of polycyclic aromatic hydrocarbons (PAH) during smoking, scientists associate smoked meat with human health risks. PAH contamination of smoked food depends on the smoking method, the temperature and the wood species. The smoking temperature and the PAH contaminations of Sámi traditional *lávvu*-smoked reindeer products yet remain uninvestigated. To remedy this knowledge gap, we developed a unique co-produced *lávvu-laboratory* pilot study for temperature measurements and PAH analysis of smoked reindeer meat with different Arctic wood species (willow, birch and juniper) and plant parts (logs and twigs). Our study confirms reindeer herders understanding, that birch wood, and especially birch twigs, generate higher smoking temperatures than willow. Except reindeer meat smoked with birch twigs, PAH levels of analysed reindeer meat cuts were lower than EU recommended maximum levels. However, all smoked reindeer fat samples showed much elevated PAH contaminations. Our results demonstrate the importance of co-production including both scientific and traditional knowledge in research for increased understanding of Indigenous peoples' traditional food smoking and to insure healthy traditional smoked Arctic products.

Introduction

Direct smoking of food is a living traditional method used all over the world for preservation and flavouring [1,2]. To Sámi reindeer herding food culture, traditional smoked reindeer meat is still an important product [3,4]. However, while Sámi reindeer herders desire to sell traditionally *lávvu*-smoked reindeer meat [5], scientists are concerned that traditionally smoked meat may be unhealthy [6].

Eating smoked food may be unhealthy since direct smoking can result in Polycyclic Aromatic Hydrocarbon (PAH) food contaminations through deposition of tar aerosols from the smoke [7]. PAH is a substance group formed during incomplete combustion of organic material – some are toxic, mutagenic or carcinogenic [8,9]. Thus, the most momentous endpoint of PAH toxification is cancer [10,11].

In general, PAH levels of smoked meat products are widely studied, e.g., [12] and [13]. It is important that producers of smoked meat are aware of the risk and able to study their products' PAH levels [13]. Temperature and air flow are the main parameters affecting PAH contamination when using traditional smoking methods. The smoking temperature are mainly affected by the wood species used [12].

The highest PAH levels appear in meat smoked using traditional direct smoking methods [12,14]. Indeed, "*High contents of genotoxic and carcinogenic compounds in food were in the past and are presently still linked to poor production practices*" [15]: (s. 276). However, since "traditional smoking methods" are diverse, and since scientists have not yet documented PAH levels of *lávvu*-smoked reindeer meat [4,16], it is impossible to draw conclusion on the healthiness of traditional smoked reindeer meat. Thus, the food safety of such a regional product might be jeopardised.

This paper aims to bridge Sámi reindeer herders' traditional knowledge and scientists' knowledge of smoking for food safety. Indigenous knowledge and science may show both similarities and dissimilarities, and "bridging" them can capture potential synergies by combining complementary knowledge, skills and capabilities resulting in "co-production of knowledge" that neither party can produce alone [17].
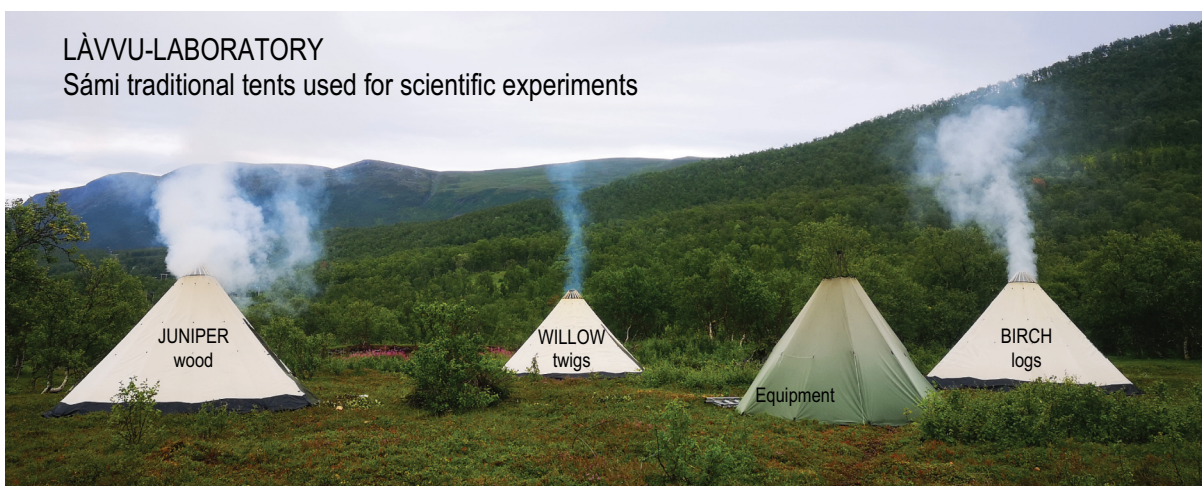
Figure 1. In the *lávvu*-laboratory Sámi traditional knowledge and scientific knowledge of reindeer meat smoking is studied through co-production experiments in three identical Sámi tents (*lávvus*). Reindeer meat is smoked using different wood species and plant parts e.g., juniper wood, willow twigs and birch logs as illustrated (the green *lávvu* is used to store equipment). The smoke appearance and temperature are investigated, and smoked reindeer meat and fat samples are taken for chemical PAH analysis.

To bridge the traditional and scientific knowledges of smoking, we developed an innovative multidisciplinary co-production method – a *lávvu-laboratory* – where we performed scientific experiments based on Sámi reindeer herders' traditional knowledge. As a case, this pilot study explores Sámi *lávvu*-smoked reindeer meat through smoking temperature measurements and PAH analysis. Experiments are variated using different firewood species and plant parts – defined as the specific living states of the plant; the stem (referred to as logs with or without bark) and the living branches (twigs with or without leaves). See figure 1.

Background

Sámi indigenous traditional food systems in revision

Sámi reindeer herders are an Indigenous people in Norway, Sweden, Finland and Russia. This paper focus on the Indigenous traditional knowledge of some Sámi reindeer herders in Finnmark, Northern Norway. A general definition of Indigenous knowledge – in our case referred to as Sámi reindeer herders' traditional knowledge – is given by the Inuit Circumpolar Council-Alaska [18, p. 7]:

"Indigenous Knowledge is a systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons and skills. It has developed over millennia and is still developing in a living process, including

knowledge acquired today and in the future, and it is passed on from generation to generation".

While Alaskan Inuit are documented to hold own knowledge system for food sovereignty [18], the Sámi food sovereignty is barely discussed and the Sámi traditional knowledge are poorly recognised in mainstream food knowledge systems in the Norwegian part of Sápmi – the land of Sámi people [19,20]. This generates consequences for Sámi reindeer herders, since knowledge of sustainable food systems and traditional food security in Sápmi is likely a key to develop future systems of food security and sovereignty among Sámi and other peoples in the North [21]. In addition, since the 1960s, major changes and regulations have occurred and impacted the food production in Sápmi. For example, to date, because of the health issues related to smoking in general, the Norwegian Food Safety Authority (FSA) requires smoking performed indoors and suggest prohibiting *lávvu*-smoking by law unless it can be proved safe [22]. This despite that traditional *lávvu*-smoking have not yet been investigated according to carcinogenic PAH. Such changes and regulations may have impacted regional and traditional smoking practices, Sámi food sustainability and safety, and human health.

Further, increased distance between the food production systems and the consumers do disconnects people from the biosphere. Revision of today's food system to include more efficient use of natural resources in food production and enhancing the resilience of production systems and the biosphere is needed [23] . Correspondingly, we argue for actions to better understand reindeer herders' traditional food

knowledge, to safeguard Sámi traditional food practices, make it resilient, and to improve its stewardship. This paper can be seen as a starting point in this regard.

Sámi meat smoking and health

Arctic Indigenous Peoples and even Sámi reindeer herders within Finnmark have different meat smoking practices and knowledges. In general, reindeer herders often smoke reindeer meat by hanging it near the top opening of their traditional tents – *lávvu* in Sámi [4]. Traditional knowledge of *lávvu*-smoking hold by consulted Sámi herders in Finnmark rich, complex and linked to the Arctic local wood species and plant parts used: Either these Sámi herders use willow or birch, maybe combined with juniper, to generate smoke. Some herders only add fresh wood to the smoking fire, others combine it with dry wood. Some herders only use wood logs, other combine it with twigs with or without leaves [24]. In contrast to industrial smoking chambers, which use temperature to assess the smoking, reindeer herders use their human sensor to avoid too hot fires and smoke [16].

Reindeer herding Sámi have lower cancer risk in general, but increased risk of stomach cancer. Since the Sámi were relatively late in using refrigerators and freezers, their increased cases of stomach cancer are suggested connected to mould in the food (aflatoxin] or high consumption of smoked and salted meat [25,26]. Thus, by eating smoked reindeer meat, Sámi reindeer herders may jeopardise own health. Similar conclusions regarding traditionally smoked meat and human cancer have been made e.g. in Iceland [27] and Nigeria [28]. However, not only the specific food but also consumption frequency and meal sizes are essential when balancing health benefits and risks of a diet [29].

Reindeer herders' traditional knowledge, including their rich knowledge enrolled in the smoking practice, is strongly coupled to the environment, the culture, the society and the health of reindeer herders. Smoking was necessary for preservation especially in the past, but still today *lávvu*-smoked reindeer meat is a preferred taste in Sámi households and an important part of the Sámi diet. However, climate change, land use changes and globalisation threaten reindeer herders' traditions in general and food traditions in specific. To reindeer herders', sustainability means to use their own knowledge to overcome these challenges and to develop their own (food) society, culture and traditions [3].

PAH contamination and smoking temperature

Smoke generation methods in general use most often sawdust – second most wood or woodchips burning. Smoking methods with smoke temperatures < 35°C are defined as cold smoking methods, 35–50°C as warm smoking and > 50°C as hot smoking [30]. When biomass gasification and pyrolysis exceed 750°C, tertiary tar products (PAHs) are formed. The PAHs may be transported as tars aerosols to deposit on the smoked meat product [12].

Benzo[*a*]pyrene (BaP) has previously been seen as an indicator for the PAHs occurrence in food. However, to date as much as 16 PAHs (often referred to as the 15 + 1) are seen clearly as genotoxic carcinogens by the European Food Safety Authority (EFSA) Panel on Contaminants in the Food Chain (CONTAM Panel) [30,31]. Eight PAHs (PAH8) are currently the only possible indicators of carcinogenic potency of PAHs in food. Yet, PAH8 do not provide much added value compared to PAH4: the sum of benzo[*a*]pyrene, chrysene, benz[*a*]anthracene and benzo[*b*]fluoranthene. Thus, PAH4, and not benzo[*a*]pyrene, is currently seen as a suitable indicator for the occurrence of PAHs in food [30]. Based on this, the European union have set maximum levels for BaP and PAH4 in smoked meats and products: currently 2.0 µg/kg wet weight [32] and 12.0 µg/kg wet weight, respectively. Separate maximum level for BaP is maintained to ensure previous and future data comparability [32].

To reduce PAH in food smoking, 10 different variables are recommended controlled by the International Food Safety Standard CAC/RCP 68/2009: the smoking method, the smoke generating process, the wood, the distance and position to the product, the fat content, the smoking time, the temperature, the cleanliness of equipment, and the design of the smoking chamber. Smoke generation temperature are seen the most important parameter influencing PAH content [33]: BaP concentration increase with increasing smoking temperatures [30]. Glow temperature between 500 and 600°C secure low PAH levels and still preserve acceptable smoke odour and flavour [33]. No correlation are found between PAH content, and the moisture of the wood chips and the maximal *smoke generating temperature* (in this paper referred to as *glow temperature*), respectively [34].

The wood chosen for smoking is another critical parameter diminishing the contamination of food products [35]. Several studies have examined smoked meat PAH levels of different wood species, e.g., [34] and [35]. Beech wood is most commonly used for food smoking

[31]. Yet, selecting alternative wood species are suggested, since several wood species (except alder and beech spiced with cherry) resulted in lower PAH contents compared to beech-smoked sausages [34]. The lowest PAH level, reduced by 35–55% compared to beech, has been displayed in sausages smoked with poplar or hickory wood chips. Alder showed slightly higher PAH levels compared to beech [34]. However, contradictions exist on which wood species that result in lowest PAH content. While meat smoked with alder, beech and beech spiced with cherry have displayed higher PAH content compared to spruce [34], pork meat smoked with apple or alder have displayed lowest PAH levels compared to the highest PAH content in meat smoked with spruce [35].

Indirect and alternative methods are considered healthier than traditional methods because it may lead to less PAHs [12]. However, smoke houses or constructions differ in size and equipment. Thus general statements on exact measures needed to lower the PAH concentrations in specific products are not possible [13]. Therefore, we argue that, before stating a Sámi product or method as health hazardous, one should make sure what methods they use and how this affects the PAH contaminations of the smoked meat.

Only one scientific study and two reports have previously determined the PAH levels of traditional smoking of reindeer meat [4]: lean reindeer meat indirect smoked with willow logs (were <0.3 µg/kg or n.d., respectively. Only elk combined with reindeer meat smoked by direct "sauna" using willow logs exceeds BaP and PAH4 above EU maximum levels (6.6 µg/kg and 35.8 µg/kg, respectively) [13]. But, the so-called "sauna" smoking method (basturökning in Swedish) used on the products analysed in the programme is not a traditional Sámi smoking technique, since they refer to Hartman [36, p. 265], which refer to Ryd [37] which finally describe the Sámi tradition as different. In a report for the Norwegian FSA only one sample of reindeer meat were analysed ([BaP: <0.5µg/kg ww; PAH4: 0µg/kg ww]) [38]. They did not state the smoking method used. In contrast, chemist and ethnolog Astri Riddervold analysed reindeer meat smoked by a traditional method using willow wood in a Sámi lávvu. However, these results are only published in a non-scientific report [6].

Therefore, to date, no published data on the PAH levels of traditional Sámi smoked reindeer meat exist. Neither have herders knowledge and practice of different arctic wood species and plant parts used for smoking been investigated regarding smoking temperature [4]. Our study fills this knowledge gap.

Materials and methods

Lávvu-laboratory co-production

We named our method the lávvu-laboratory, because it includes scientific experiments and investigations of traditional smoking performed in the Sámi lávvu (traditional tent) (Figure 1). Bringing the laboratory equipment to the field has earlier been done using transportable laboratories in polar science [39]. By imitating a scientific laboratory, including both scientific measurements and analysis, and traditional knowledge holders (Sámi reindeer herders), situated in the traditional Sámi working space – the lávvu (Figure 2), this study followed important principles for co-production [40,41].

Thus, this is a co-production, interdisciplinary and community-based study, using methodology both from health, social and natural sciences. Including herders' traditional knowledge, experiences and techniques, the data collection counts several fields of expertise. Social science ethnographic fieldwork has been performed through participant observations, conversations and semi-structured interviews, as presented in [24]. In this current paper, we used an experimental setup known from health and natural sciences to test and investigate Sámi traditional smoking techniques according to temperature measurements and PAH analysis.

Experimental set-up

The experiments were performed at the coast of northern Norway during three days in August 2020, by the following procedure: we 1) harvested the firewood; 2) pitched the experimental lávvus and arranged fireplaces and temperature sensors inside; 3) thawed, butchered and salted (14 hours) the reindeer meat cuts ahead each experiment trial; before 4) weighing and hanging one in each lávvu. Then, we 5) registered outside air temperature (11–16°C) and weather conditions (mild wind, sunny, cloudy, and only short periods of mild rain – if any); and 6) started the temperature loggers; before 7) starting a fire in each lávvu using small amounts of dry birch wood. During the smoking process, we 9) only added the wood species and plant parts tested in each individual trial; and we 10) noted macro-observations and photographed the smoked meat cuts, the fires and the smoke. After five hours smoking, we 11) hung the smoked meat cuts out of the smoke to cool (2 hours) before weighing, packing (1 hour), and collecting separate meat and fat samples. Then last, the samples were 12) frozen, and 13) the temperature data logged on a computer.

Figure 2. Scientists and reindeer herders research together in the *lávvu*-laboratory. The data-collection included glow and smoke temperature measurements, smoked reindeer cut samples for PAH-analyses, photo-documentation, dialogues, common observations, and sensation of the smoking practice.

The wood

Eight different local wood species and plant parts were tested: Birch (*Betula pubescens*) logs without bark; birch logs with bark; birch twigs with leaves; birch logs with bark combined with twigs with leaves; willow (*Salix caprea*) logs with bark; willow twigs with leaves; willow logs with bark combined with twigs with leaves; and juniper (*Juniperus communis*) twigs. All local wood were fresh and harvested, 1–5 days before use, at the coast of northern Norway. Wood logs were cut in ~95 cm length and the average diameter was 5.10 cm. The twigs were shorter and narrower (1–3 cm).

One industrial manufactured wood was tested: Beech logs and chips. The beech logs were 95 cm length and 72 × 72 cm thick, made of 100% fibre *Beech Räuchergold friction logs* imported from J. Rettenmaier & Söhne gmbh + co kg (JRS), Rosenberg, Germany. The beech chips were *Beech Räuchergold wood smoking chips* kl. 2–16 at 6–12 mm (the type mostly sold), produced by JRS (batch no. 189) and imported through Bokken AS, Norway.

Wood humidity was measured using a *Brennenstuhl moisture detector MD* (Art no. 1,298,680) for three randomly selected measurements of the mean moisture in the wood, in the bark, and in the leaves (if any) of all tested firewood.

The lávvus

Three identical Sámi *lávvu*s (I, II, and III in Figure 3) made by *Arctic Lavvo of Kautokeino* (type: "Venor") were used for the experiments. The *lávvu*s consisted of erected aluminums poles and a cotton-polyester canvas, generating a diameter of 470 cm, a floor area of 17.3 m^3, and a height of 273 cm (see Figure 1). Inside the *lávvu*s, stones were arranged in the middle to define the fireplace (~1 m diameter). The meat cuts were hung directly above the fireplace (150 cm meat cut tip-ground) on a bar near the *lávvu* top-opening (Figure 3; Figure 4A).

Glow and smoke temperature loggers

For smoke and glow temperature measurements, three Thermopar ThermaData Logger TCD (Art no. 292–501, LCD) were used, with a range of −100°C to 1 372°C, 0.1°C resolution and ±0.4°C accuracy. Connected sensors included six Thermadata® thermocouple mineral-insulated bendable probes (order code 133–429; 3 ×
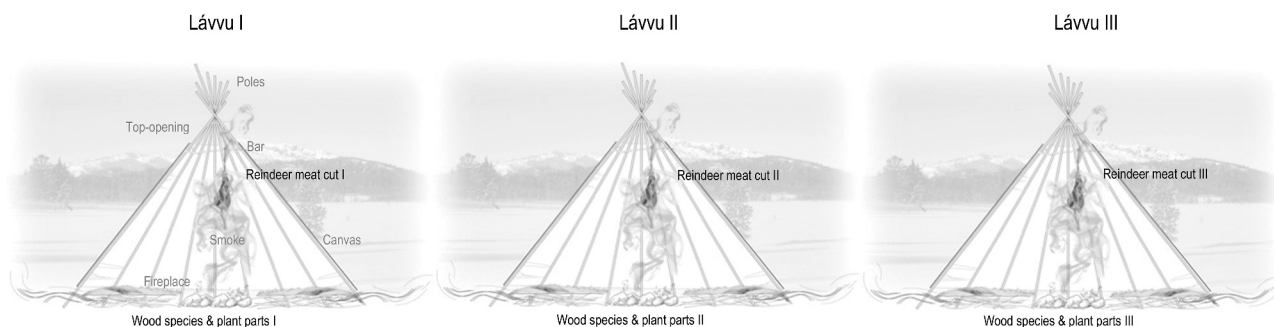
Lávvu I Lávvu II Lávvu III

Figure 3. The experimental set-up of the *lávvu*-laboratory includes three identical *lávvu*s, each with a fire of different wood species and plant parts, and in the top-opening reindeer meat is hung to be smoked.
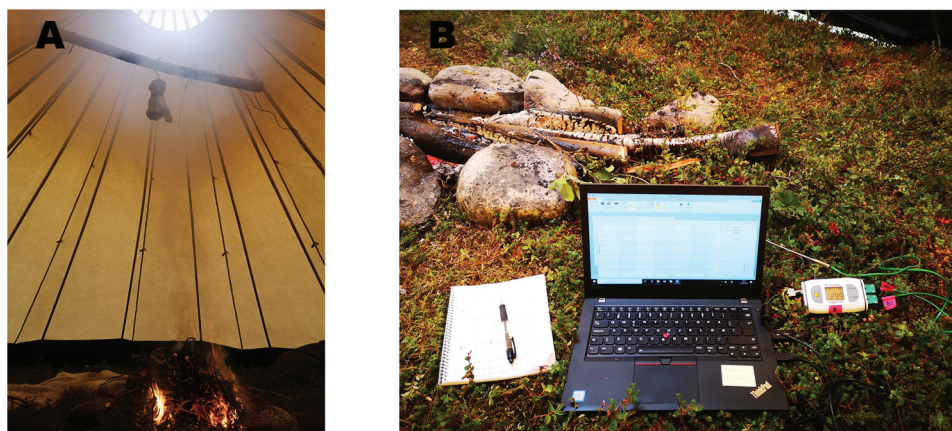

Figure 4. The thermometer (right in picture b) is coupled to two sensors: one in the fire (picture b) and one by the meat (picture a). After smoking, the temperature data were logged on a computer (picture b).

1000 mm diameter, 5 m length) with a range of −200°C to 1 100°C and a response time < 4 s.

The temperature loggers were arranged with two sensors each; one in the fireplace (glow temperature) and one hanging by the meat (smoke temperature), see Figure 4. The temperature log interval was 30 s. As appearing in Figure 4, all data were logged to a computer using the Software program for ThermaData Studio 5.0.0 (available at https://thermo meter.co.uk/content/170-software-apps).

Since the fire start-up process in each lávvu was not simultaneal, a data selection of each temperature log was performed; 2.5 hours after the last fire was started, until removing the meat cuts from the smoke. From the selected data, mean, minimum and maximum temperatures, including population standard deviation (SD), were calculated.

The reindeer meat

The meat cuts used in the experiments included four leg parts of two reindeer of equal sex, size, condition and age; fat female reindeer without calves selected and slaughtered traditionally by a Sámi reindeer herder in Finnmark and thereafter frozen (March 2020). The meat cuts included both a subcutaneous fat layer and an inner meat part, and each were marked with a sample ID. Most meat cuts were ~1700 g before smoking – except the meat cuts smoked with birch logs + twigs (E1B), and willow logs + twigs (E1S) – which were ~600 g. Each meat cut was salted with 32 g coarse sea salt (*Jozo Havsalt Middelhavet*, extra coarse 05).

Since PAHs are lipophilic, outer fat samples and inner meat samples of the smoked reindeer cuts were collected for separate analysis: meat samples were collected from inner, outer and middle area of the meat (~300-400 g) – fat samples from the outer subcutaneous fat layer (~30-120 g). One non-smoked meat and fat sample were collected. In addition, samples of reindeer meat and fat smoked by two individual Sámi reindeer herders were collected (willow & some juniper; birch & lots of juniper, respectively). Before sending for analysis, all samples were packed separately in

aluminium foil (innermost) and two plastic bags (outermost) and frozen at −20°C.

Chemical analysis of smoked reindeer meat

The chemical analysis of the PAH, fat and water content of the smoked reindeer meat and fat samples was performed by the Norwegian Institute for Air Research (NILU), accredited according to ISO/IEC-17025.

For fat content determination of the smoked reindeer meat and fat samples, parallels are taken: Two beakers (~ 50–100 ml) were placed in a heating cabinet at 110°C (1 hour), and thereafter cooled in a desiccator (minimum 30 min). The quantity of the sample (including sodium sulphate) was weighed and divided into two equal parts and transferred to separate glass columns with cotton. Pre-weighed beakers were placed underneath and ca. 100 dichloromethane was transferred. The beakers, with a perforated lid of aluminium foil, were put in an extractor. When all solvent had evaporated, they were heated in a cabinet at 110°C (1 hour). Next, the glasses were transferred to a desiccator to be left for a least 30 min. Last, the glasses were weighed and the fat percentage calculated.

For dry matter determination of the smoked reindeer meat and fat samples, the following procedure was used: 1–10 g of each sample was weight and placed in a heating cabinet at 110°C (2 hours). Thereafter, the samples were placed in a desiccator and weighed after approximately 30 min. Heating in an oven (2 hours) and tempering in a desiccator were repeated until constant weight (dry weight) was reached. Percentage of dryness was calculated by the difference between the weighed sample and the dried sample divided by the weighed sample, multiplied by 100%.

For PAH content determination of the smoked reindeer meat and fat samples, the method NILU-O-3 was used as following: first each sample was homogenised and added deuterium-labelled internal standard. A cold-column-elution with cyclohexane and ethyl acetate as eluting solvent were performed. The extract was volume reduced to about 0.5 mL and transferred to a separating funnel for liquid: liquid extraction. After extraction, the samples were again volume reduced and purified on a column filled with deactivated silica. The purified concentrated extract was added to a recovery standard before analysis on a gas chromatography-mass spectrometry (GC-MS), to identify 42 different components of the meat.

PAH concentrations from NILU were given in ng/g dry weight. For comparison to EU maximum levels, conversions to µg/kg wet weight (WW) from the dry matter content (DW) were performed (NB 1 µg/kg = 1 ng/g), using the following equation:

$$[WW] = [DW] \; x \; \% \; DW \qquad (1)$$

Totally 18 meat samples and four fat samples smoked in the *lá*vvu-laboratory experiments were analysed. Additional two meat samples and two fat samples smoked traditionally by Sámi reindeer herders with, *birch logs + twigs & lots of juniper* and *willow logs + twigs & some juniper*, were analysed.

To gather information of variations within individual meat samples, we analysed three identical batches (n = 3) of four of the meat cuts: smoked with *birch logs w/bark; willow logs w/bark; birch logs + twigs;* and *willow logs + twigs*. PAH4 mean concentrations and SD were calculated for the identical batches (n = 3), for all birch wood smoked samples (n = 4) and willow smoked samples (n = 3), respectively, and for all analysed fat samples (n = 5) and related meat samples (n = 5).

Ethical considerations

This study was approved by Norwegian Centre for Research Data (NSD), Project #54964. National and international ethical guidelines for studies on indigenous and reindeer herding peoples' issues were followed [42–47].

Results

Moisture of the wood

The moisture of the leafs and the wood bark was higher than inside the wood (Table 1). Highest moisture content (>48%) were registered in *birch logs w/bark; willow logs w/ bark;* and *willow twigs*. Lowest wood moisture contents were registered in *juniper twigs* (27%); *birch logs w/o bark* (26%); *beech logs* (12%); and *beech chips* (5%).

Fat and dry matter content of the smoked meat

The fat content of the smoked meat samples varied from 2.0 to 8.4% (mean 4.1%) and of the smoked fat samples from 70 to 86% (mean 76%). Dry matter content of the smoked meat samples varied from 20 to 43% and of the fat samples from 83 to 90% (97% for the traditional birch-smoked sample, and 52% for the traditional willow-smoked sample. The meat cuts' average weight reduction was 6.3% after salting and smoking.

Table 1. Mean moisture (%) of wood selected for smoking in the *lávvu*-laboratory, and related fat and dry matter content of analysed smoked reindeer meat and fat samples. Weight reduction (%) of the reindeer cuts after salting and smoking appear. Meat and fat sample R1; R2; R3; and R4 is smoked by traditional Sámi reindeer herders.

SMOKING WOOD					SMOKED REINDEER CUTS				
	MOISTURE %				% FAT		% DRY MATTER		%
SPECIES – PLANT PART BIRCH	In bark	In wood	In leaf (chips)	Sample ID	MEAT	FAT	MEAT	FAT	Weight reduction
BIRCH									
Birch logs w/o bark	-	26	-	**B1**	8,4	-	40	-	7,8
Birch logs w/ bark	49	37	-	**A2**	3,9; 3,7; 3,1**	70	33; 43; 43**	87	6,9; 4,6*
Birch twigs w/ leaves	42	29	48	**C1**	5,9	76	36	83	8,1
Birch logs w/bark + twigs w/leaves	-	-	-	**E1B**	5,3	-	37	-	13,5
WILLOW									
Willow logs w/ bark	>50	40		**B2**	2,8; 2,4; 2,0**	75	33; 27; 27**	90	5,9
Willow twigs w/ leaves	49	37	48	**D2**	4,9	75	37	90	4,5
	-	-	-	**E1S**	4,8	-	20	-	9,4
JUNIPER									
Juniper twigs	39	27	-	**E2**	3,0	-	33	-	7,0
BEECH									
Beech friction logs w/o bark + chips	-	12	(5)	**C2**	3,7	86	32	87	6,8
MEAN					**4,1**	**76**	**34**	**87**	**6,3**
Traditional smoked w/ **birch** & lots of **juniper**	-	-	-	**R2; R1**	3,4	93	40	97	-
Traditional smoked w/ **willow** & some **juniper**	-	-	-	**R4; R3**	2,4	59	27	52	-
NON-SMOKED				**E1K**	6,3	78	30	87	

*n = 2; **n = 3

Glow and smoke temperatures

Glow and smoke mean, minimum and maximum temperatures of all tested wood appear in Table 1, Table 2 and Table 3, respectively.

The highest mean glow temperature was found for *birch logs w/o bark*; or *birch logs + twigs*. The glow temperature of burning *birch logs w/o bark*; *birch logs w/ bark*; *birch twigs*; or *birch logs + twigs* were 706, 489, 538 and 622°C, respectively. The glow temperature of burning *willow logs; willow twigs*; or *willow logs + twigs* were 455, 489, and 443°C, respectively. The glow temperature of burning *juniper* or *beech* were 444°C and 520°C, respectively.

The highest mean smoke temperature was logged burning *birch logs + twigs* (52°C) or *juniper* (48°C). *Birch logs w/o bark* burned with higher mean smoke temperature (44°C) than *birch logs w/ bark* (36°C). The mean smoke temperature burning *beech logs + chips* was 42°C, like *birch twigs* which was 41°C.

The lowest mean temperature was logged burning *willow twigs* (20°C), then *willow logs + twigs* (28°C), or *willow logs* (31°C).

The highest maximum smoke temperature was logged burning *birch twigs* (223°C), or *birch logs + twigs* (208°C). Burning *birch twigs* generated several high smoke temperature peaks throughout the

Table 2. Glow temperature mean, minimum, and maximum (°C) of the different wood species and plant parts used for smoking in the *lávvu*-laboratory.

SMOKING WOOD	GLOW TEMPERATURE °C		
SPECIES – PLANT PART	MEAN ±SD	MIN	MAX
BIRCH			
Birch logs w/o bark*	**706** ± 83	490	861
Birch logs w/ bark**	**489** ± 176	133/160	750/756
Birch twigs w/ leaves	**538** ± 88	396	744
Birch logs w/bark + twigs w/leaves	**622** ± 123	431	811
WILLOW			
Willow logs w/ bark	**455** ± 205	75	868
Willow twigs w/ leaves	**489** ± 86	304	751
Willow logs w/ bark + twigs w/leaves	**443** ± 125	129	693
JUNIPER			
Juniper twigs	**444** ± 55	352	601
BEECH			
Beech friction logs w/o bark + chips	**520** ± 139	338	827
MEAN			
Traditional smoked w/ **birch** & lots of **juniper**	-	-	-
Traditional smoked w/ **willow** & some **juniper**	-	-	-
NON-SMOKED	-	-	-

* temperature logs from when the fire extinguished is not included; **mean of two experiments

Table 3. Smoke temperature mean, minimum and maximum (℃) of the different wood species and plant parts used for smoking in the *lávvu*-laboratory.

SMOKING WOOD	SMOKE TEMPERATURE ℃		
SPECIES – PLANT PART	MEAN ±SD	MIN	MAX
BIRCH			
Birch logs w/o bark*	**44** ± 11	22	70
Birch logs w/ bark**	**36** ± 9	19/21	54/91
Birch twigs w/ leaves	**41** ± 31	20	223
Birch logs w/bark + twigs w/leaves	**52** ± 21	27	208
WILLOW			
Willow logs w/ bark	**31** ± 10	20	65
Willow twigs w/ leaves	**20** ± 5	14	36
Willow logs w/ bark + twigs w/leaves	**28** ± 6	18	47
JUNIPER			
Juniper twigs	**48** ± 28	19	145
BEECH			
Beech friction logs w/o bark + chips	**42** ± 10	25	72
MEAN			
Traditional smoked w/ **birch** & lots of **juniper**	-	-	-
Traditional smoked w/ **willow** & some **juniper**	-	-	-
NON-SMOKED	-	-	-

* temperature logs from when the fire extinguished is not included; **mean of two experiments

Table 4. Smoked reindeer meat and fat BaP and PAH4 contentaminations from smoking with different wood species and plant parts in the *lávvu*-laboratory. Meat and fat samples R1, R2, R3 and R4 are smoked by traditional Sámi reindeer herders. Mean ±SD appear for samples with several batches analysed.

SMOKING WOOD		SMOKED REINDEER CUTS			
		[PAH] (ng/g wet weight)			
		MEAT		FAT	
SPECIES – PLANT PART	Sample ID	BaP	PAH4	BaP	PAH4
EU maximum PAH levels 2011		2	12	2	12
BIRCH Mean± SD			**29.4 ± 39.5**		
Birch logs w/o bark	B1	0.5	3.2	-	-
Birch logs w/ bark (n = 3)	A2.1	0.2	1.3	-	-
Mean ± SD	A2.2	0.3	1.7		
	A2.3	0.2	1.5		
		0.2	1.5 ± 0.2		
Birch twigs w/ leaves	C1	2.9 [x]	15.8[x]	13.2 [x]	127.3[x]
Birch logs w/bark + twigs w/leaves (n = 3)	E1B.1	13.6	90.2	-	-
Mean ±SD	E1B.2	13.3	95.5		
	E1B.3	15.1	105.8		
		14.0	97.2 ± 6.2		
WILLOW Mean± SD			**5.4 ± 1.7**		
Willow logs w/ bark (n = 3)	B2.1	1.1	6.8	-	-
Mean ±SD	B2.2	0.8	3.9		
	B2.3	0.9	5.1		
		0.9	5.2 ± 1.2		
Willow twigs w/ leaves	D2	0.5 [x]	3.4[x]	3.1 [x]	22.3[x]
Willow logs w/ bark + twigs w/leaves (n = 3)	E1S.1	1.1	7.7	-	-
Mean ± SD	E1S.2	1.1	7.9		
	E1S.3	1.0	7.1		
		1.1	7.6 ± 0.4		
JUNIPER					
Juniper twigs	E2	1.7	11.0	-	-
BEECH					
Beech friction logs w/o bark + chips	C2	0.1 [x]	0.8[x]	2.5 [x]	18.2[x]
Traditional smoked w/ **birch** & lots of **juniper**	R2; R1	1.8 [x]	10.0[x]	5.1 [x]	32.4[x]
Traditional smoked w/ **willow** & some **juniper**	R4; R3	1.4 [x]	7.2[x]	5.4 [x]	32.6[x]
Mean ± SD (only include PAH-data marked with x; n = 5)		1.3	**7.4 ± 5.2**	5.9	**46.6 ± 40.8**
NON-SMOKED reindeer meat	E1K	0.04	<0.2	<0.1	<0.5

smoking process (Figure 5). High smoke temperature peaks are not present when burning *birch logs* (54°C and 70°C *w/ and w/o bark,* respectively). Burning *juniper* also resulted in high smoke temperatures (max 145°C) and several high temperature peaks (Figure 7).

The lowest maximum smoke temperature was logged burning *willow twigs* (36°C). No high smoke temperature peaks appear for either *willow logs; willow twigs;* or *willow logs + twigs* (Figure 7), nor *beech logs + chips* (Figure 8).

PAH contamination

BaP and PAH4 contamination levels of all reindeer meat and fat samples analysed appear in Table 4, and in relation to smoke temperature in Figure 9. Much higher [PAH4] mean and variations (n = 5) was found for the smoked fat samples (46.6 ± 40.8 µg/kg ww) compared to the smoked meat samples (7.4 ± 5.2 µg/kg ww). All smoked fat samples analysed contained PAH4 above EU max levels; 12 µg/kg ww. All smoked meat samples analysed contained PAH4 lower than EU max levels – except those smoked with *birch twigs* (15.8 µg/kg ww) or *birch logs + twigs* (97.2 µg/kg ww).

The highest PAH4 meat contaminations were found smoking with *birch logs + twigs* (mean 97.2 ± 6.2 µg/kg ww). The lowest PAH4 meat contaminations were found smoking with *beech logs + chips* (0.8 µg/kg ww).

Minor variations in [PAH4] between samples taken from the same smoked meat batch were found 1.5 ± 0.2; 97.2 ± 6.5; 5.2 ± 1.2; 7.6 ± 0.4 (n = 3). We found wide variation in [PAH4] between meat samples smoked with different plant parts of birch 29.4 ± 39.5 (n = 4) and minor variation between samples smoked with different plant parts of willow 5.4 ± 1.7 (n = 3).

Descriptive sensorial findings

All fires had a constant rise of smoke passing the meat before leaving the *lávvu* top-opening. The *birch twigs* or *juniper* fire occasionally blow up in high flames with lots of particles flying up settling on the meat cuts (Figure 5 C1; Figure 7 E2). The *willow twigs* fire did not generate high flames, but instead produced an evener smoke rise, with few leafs flying up and sticking to the meat cuts (Figure 6). The *juniper* fire produced lots of smoke (see Figure 1), before it flamed. Both logs of birch, willow and beech produced calm fires and meat cuts free from particles (Figure 5 B1; Figure 5 A1/2; Figure 6 B2; Figure 8 C2).

The willow-smoked reindeer meat was redder in colour (Figure 6), compared to the birch-smoked (Figure 5). The juniper-smoked meat was light red, the beech-smoked meat very dark red (Figure 7 and 8).

Discussion

First, we discuss the three main findings of this pilot study on *lávvu*-smoking reindeer meat cuts smoked with Arctic wood.

1) Subcutaneous smoked reindeer fat contained increased PAH compared to smoked reindeer meat.

2) Burning willow generated cold smoke, burning birch or juniper generated warm smoke. Depending on wood species, different plant parts effected the smoke temperature and the reindeer meat PAH concentration differently. Only smoking with *birch logs + twigs* resulted in very high meat PAH contamination.

3) Several very high peaks in smoke temperature – not high mean smoke temperature – resulted in high PAH contamination of the smoked product.

Finally, we bridge scientific experimental findings to reindeer herders' traditional knowledges of smoked reindeer products to discuss Sámi food security.

Smoked reindeer fat vs. smoked reindeer meat

Sámi reindeer herders rely on their traditional knowledge when observing the herd before deciding which reindeer to slaughter [48]. For example for conservation by smoking, in some Sámi regions, male reindeer with rich subcutaneous fat layers was slaughtered before rut in September [49], others smoked leaner reindeer calves selected slaughtered for traditional skin-cloth-production in August [24]. However, traditional practices are affected by modernisation and rationalisation of Sámi reindeer husbandry. The traditional knowledge system of slaughtering, for example, reign in the tundra, but conflict with the Norwegian Food Safety Authority's scientific-driven knowledge used and developed in slaughterhouses since the 1950s [20]. Due to this separation of traditional and scientific-driven practices, no studies of the PAH content in reindeer fat smoked using a Sámi method have been documented before this pilot experimental study.

The rich Sámi terminology of reindeer fat indicates that fat is and have been an important part of Sámi reindeer herders' food culture [48]. Thus, if herders eat smoked fat, it is concerning that our study showed very high carcinogenic PAH4 levels in smoked reindeer subcutaneous fat compared to the inner smoked meat, regardless which wood used. Fat samples smoked with *birch twigs; willow twigs;* or *beech logs* contained 8-folds, 7-folds and 22-folds more PAH4 than their comparative meat samples. Indeed, *Birch-twigs*-smoked fat had PAH level >10-times higher than EU recommended maximum levels in food (Table 4). This finding call upon a food security system
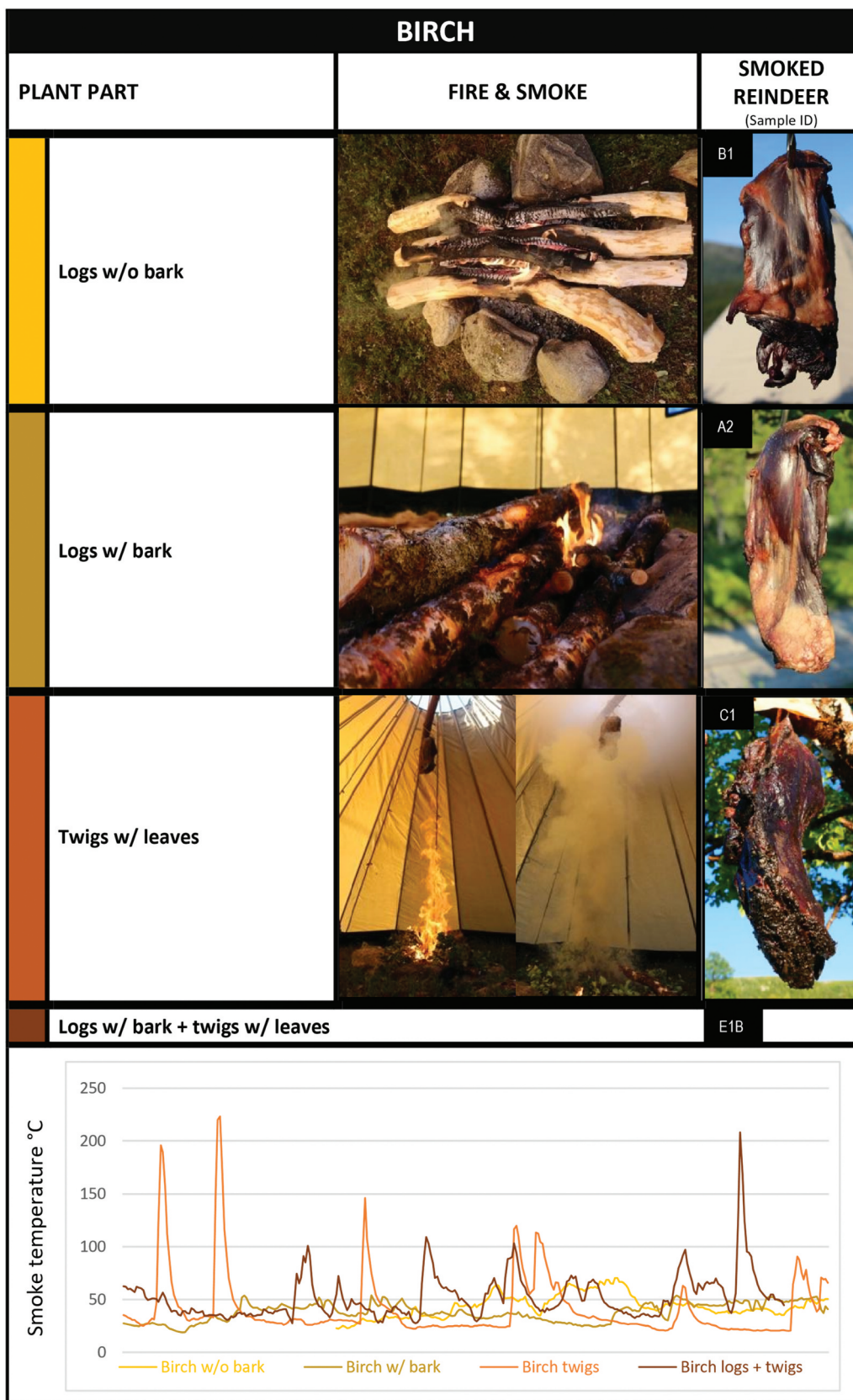
Figure 5. Smoke temperature graphs and photographs of the smoking fires and related reindeer meat cuts smoked with birch logs without bark; birch logs with bark; birch twigs with leaves; and birch logs with bark combined with twigs with leaves in the *lávvu*-laboratory.
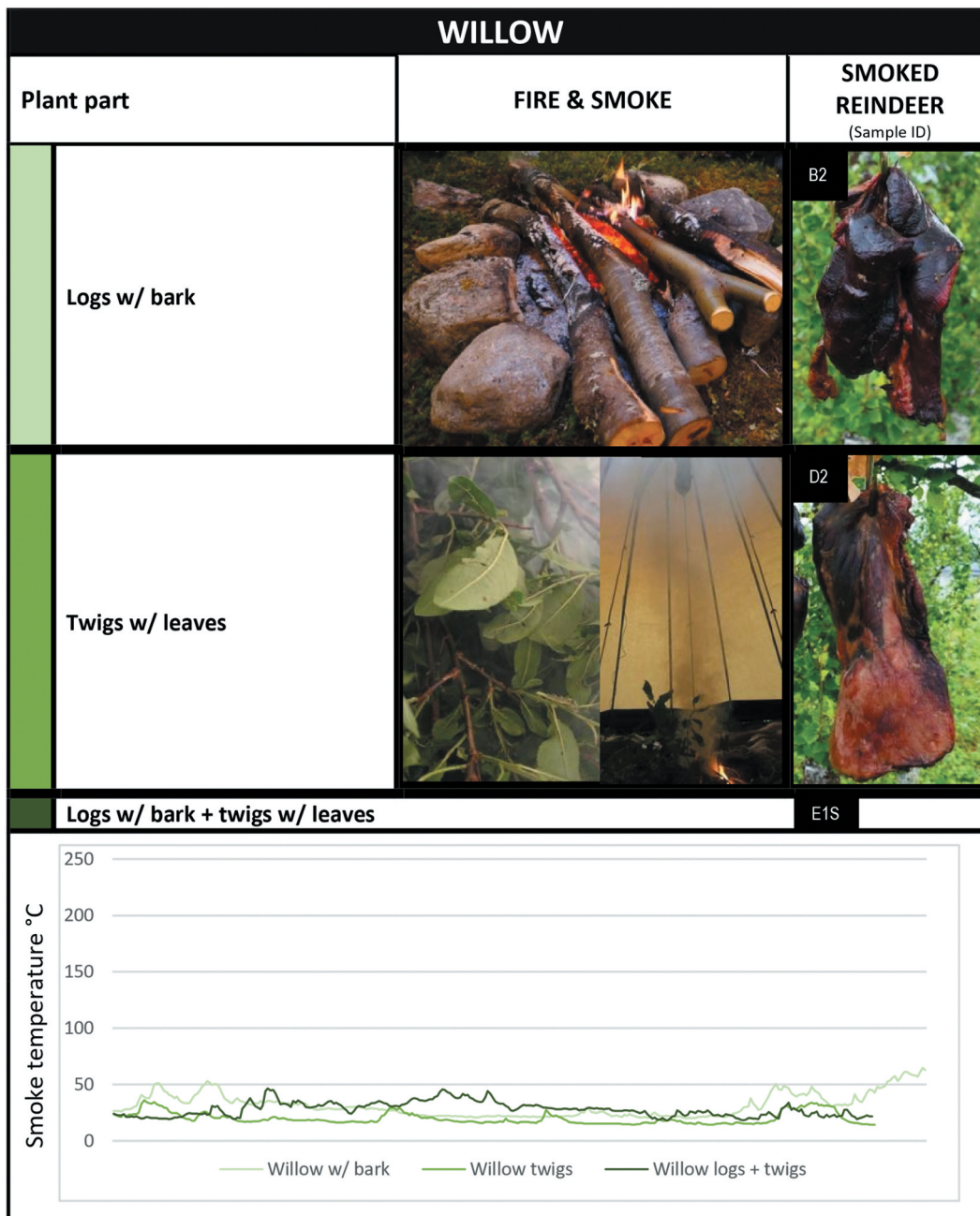
Figure 6. Smoke temperature graphs and photographs of the smoking fires and related reindeer meat cuts smoked with willow logs with bark; willow twigs with leaves; and willow logs with bark combined with twigs with leaves in the *lávvu*-laboratory.

for smoked reindeer meat rooted in Arctic reality improving individual families' food quality.

Studies on meat from other animal species show that PAHs accumulate mainly on the exterior surface [50], but that PAHs lipophilic nature may result in diffusion also to the inner layers of the product [51]. The presence of barriers, such as sausage casing [52] and bacon skin [53], is shown to interfere with PAHs migration into the product's internal layers. The water activity and the fat content have a determinant role in the migration rate of PAH into the product [54]. However,

fat content and smoking procedure not alone influence PAH. Casing type has been displayed the most influencing factor lowering PAH levels in pork collagen casing sausages [55].

These scientific findings are relevant for both modern industrial smoking of reindeer sausages and for traditional smoking of reindeer meat cuts because of its unique distribution between fat and meat. An advantage of reindeer meat is that it is relatively lean, with most fat located as a subcutaneous outer layer [56,57]. The outer fat layer of reindeer – which we show contains high PAH
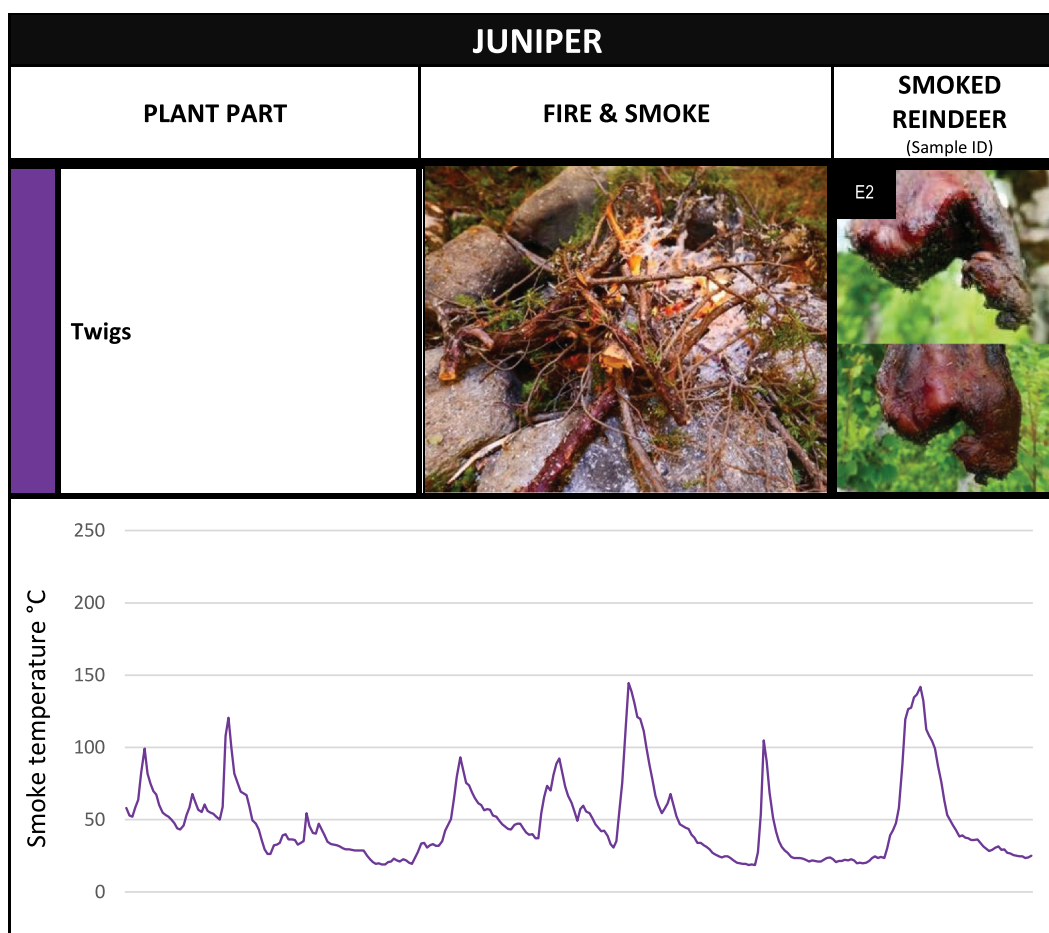
Figure 7. Smoke temperature graph and photographs of the smoking fire and related reindeer meat cut smoked with juniper twigs in the *lávvu*-laboratory.

levels when smoked – may, as casing, limit PAH diffusion to the meat. Thus, smoking reindeer meat cuts, with an outer fat layer, could result in less PAH in the meat.

However, a study on charcoal-broiled steaks showed that even if flames are not in direct contact with the meat, fat dripping onto the flames or hot coals generates PAHs [58]. PAH contamination might be reduced by simply selecting lean meat and fish and by avoiding contacts of food with flames [59]. Our study supports that smoking lean reindeer meat results in decreased PAH contamination (5.2 µg/kg ww or 1.5 µg/kg ww PAH4 in *lávvu*-smoked reindeer meat with *willow logs* or *birch logs*, respectively; Table 4), compared to e.g. smoking fatter pork meat [73.5 and 72.2 µg/kg ww PAH4 in bacon and ham meat direct smoked with willow logs, and 61.5 and 209 µg/kg PAH4 in bacon and ham direct smoked with birch logs [13].

Sámi reindeer herders have traditional knowledge of smoking less fat meat to avoid fat dripping into the fire causing high flames and are conscious about avoiding high flames when smoking – secured by adding either fresh wood logs, water or snow to a flaming fire [24,37]. We suggest that the lean nature of reindeer meat and herders' traditional strategies to avoid flames during smoking, may not only lower smoke temperature but may also lower PAH contaminations. However, the distribution of fat subcutaneously in reindeer, together with the lipophilic nature of PAH from smoking, could explain the high numbers of stomach cancer among Sámi reindeer herders shown by [25] and [26]. Thus, selection of fatter or leaner reindeer for slaughtering and smoking affects the PAH contamination of the smoked reindeer product.

Arctic wood species vs. wood plant parts

Traditionally slaughtered meat from reindeer of best meat quality is considered to be a very good and delicate food – in Sámi *hersko* [19]. The taste of smoked reindeer meat depends on local geography, family traditions and selected wood species and plant parts chosen
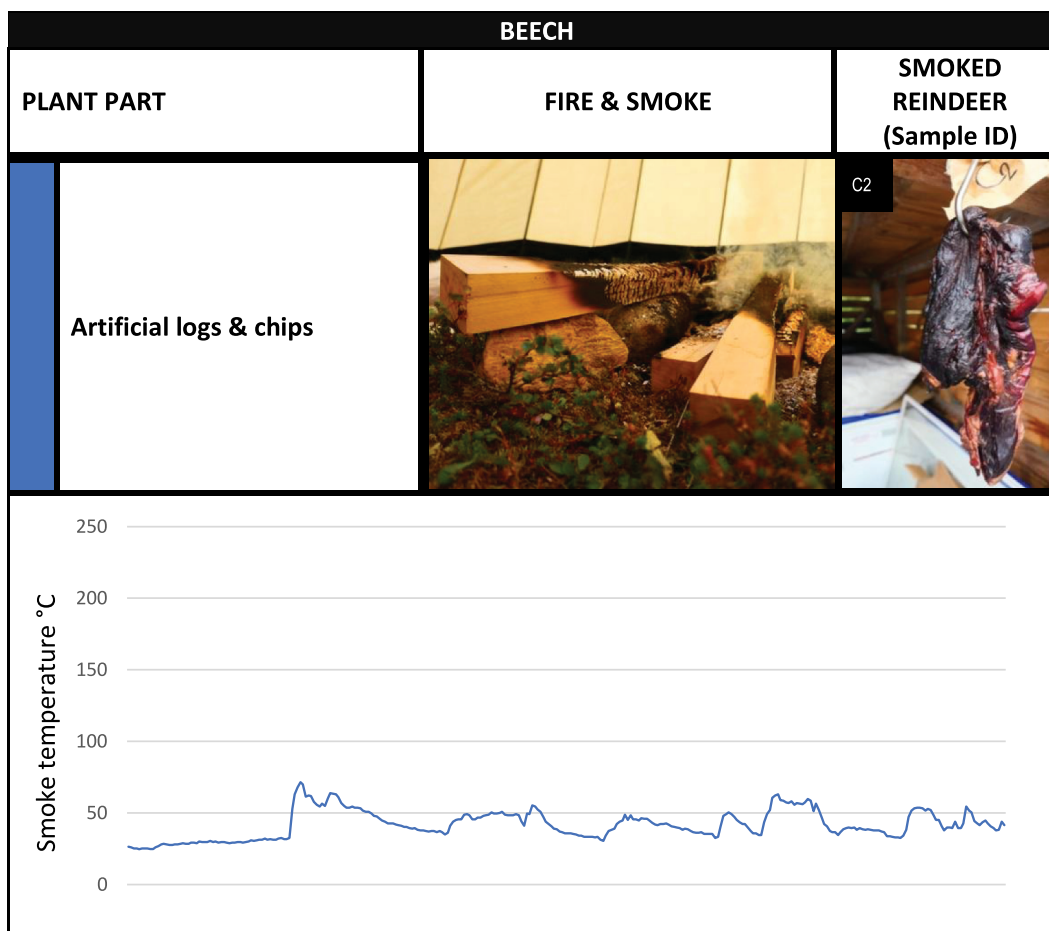
Figure 8. Smoke temperature graph and photographs of the smoking fire and related reindeer meat cut smoked with beech wood logs and chips in the *lávvu*-laboratory.

for smoking [24]. Our *lávvu*-laboratory measurements also revealed that the different wood species and plant parts used by Sámi reindeer herders result in different mean *lávvu*-smoking temperatures, effecting meat quality and colour.

According to the smoking categories defined by the EFSA [30] our willow *lávvu*-smoking is a "cold smoking process" (< 35°C), and the birch and juniper *lávvu*-smoking are "warm smoking processes" (35–50°C) (Table 3). Although throughout the smoking process, the smoke temperature of all the Arctic firewood species and plant parts tested fluctuated between cold, warm and hot smoking – except when using only *willow twigs*, then smoke temperature never exceeded 36°C. Only when combining *birch twigs + logs*, smoke temperature just exceeding 52°C, and this *lávvu*-smoking practice may thus be defined as a "hot smoking process" (> 50°C).

Burning *willow logs* and burning *birch logs* generated relative similar mean smoke temperatures (31°C and 36°C, respectively). Compared to these log-burning-temperatures, *willow twigs*-burning resulted in lower mean smoke temperature (20°C) – *birch twigs*-burning in higher mean smoke temperature (41°C). Thus, the smoke temperature is affected differently depending on both wood species (willow or birch) and plant parts (logs or twigs) used.

The different smoke temperature of different Arctic wood species is a good example of correlation between scientific and traditional knowledge. It was not unexpected that burning willow generated lower temperatures compared to burning birch. For example, among agricultural forestry researchers willow is known to have lower calorific value [60].[1] In addition, among Sámi reindeer herders burning birch are known to generate warmer fires and higher flames than burning

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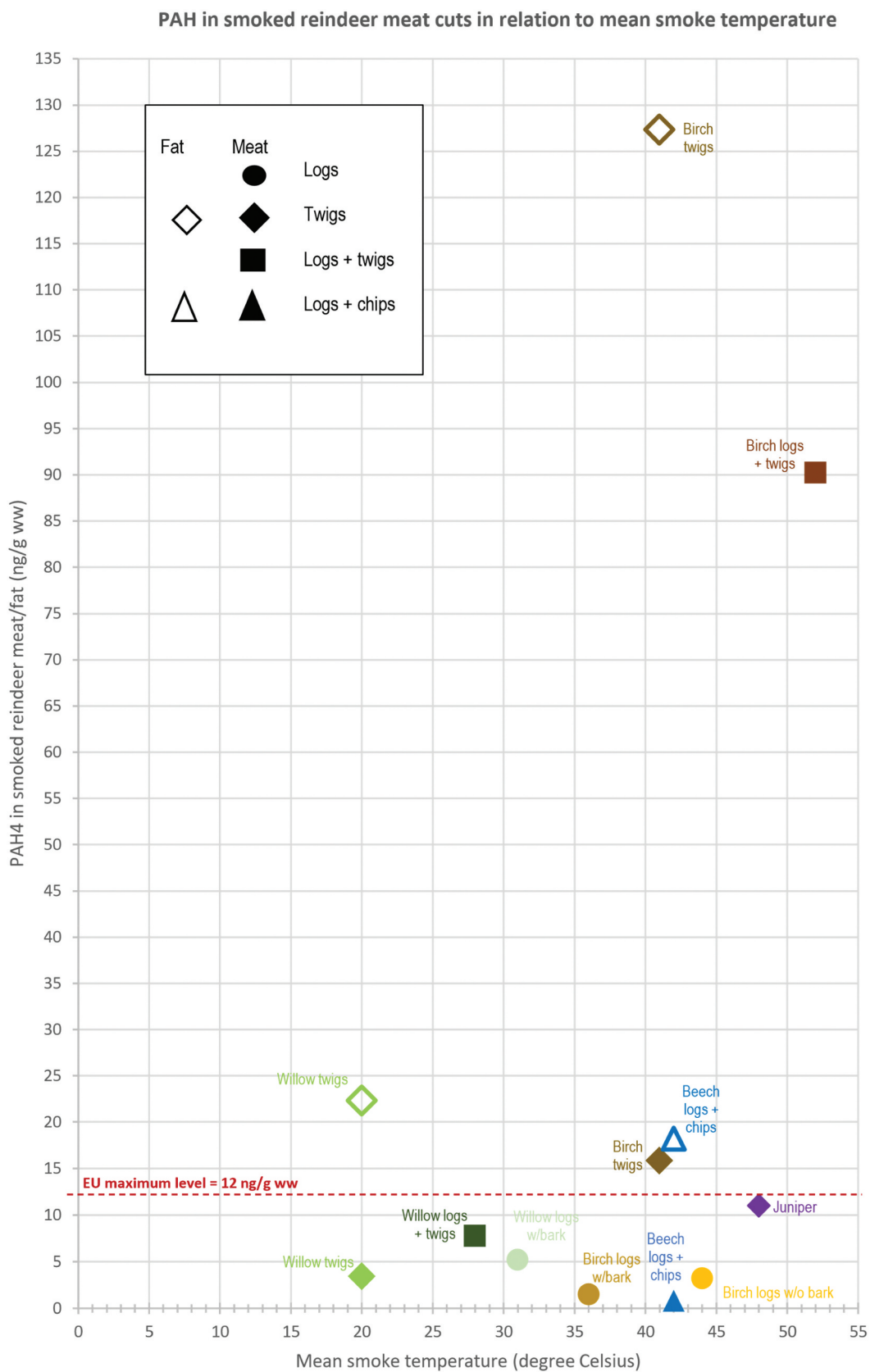[1]Note that, calorific values are given for dry wood with 0% moisture.

Figure 9. PAH4 contamination of smoked reindeer meat and fat in relation to mean smoke temperature in a Sámi *lávvu* (tent) by different wood species and plant parts.

willow. Thus, herders that smoke with willow wood – e.g. because it is easier to control the willow-fire and they prefer the willow-smoke-taste – choose birch wood for cooking food and for boiling water and coffee [24]. This shows that despite reindeer herders do not measure temperature using temperature loggers [16], they are capable to evaluate smoking temperatures based on their traditional knowledge of the fire, the smoke and the meat. Cajete (2000, p. x) expressed exactly that: *"there are 'sciences' other than the Western science of measurements"*.

The different wood species investigated in our *lávvu*-laboratory experiments revealed different PAH contamination of the smoked reindeer meat cuts (Table 4), similar to earlier findings regarding other wood species and meats [35,34]. While most of our smoked reindeer meat samples are below the EU (2011) maximum level 12 µg/kg ww (Figure 9), none of the samples smoked with Arctic wood species (birch, willow, nor juniper) had lower PAH4 levels than the sample smoked with imported commercial manufactured beech wood – the species most common used in commercial food smoking [31]. In contrast, in a study on smoked sausages most samples smoked with wood chips species [oak, spruce, poplar, hickory, beech with apple-spice mix and a mix of juniper berries and bay leaves) had lower PAH contents than the beech-smoked sausages [34].

An extraordinary finding of our study was that not only smoking wood species but also plant part (logs or twigs] effects PAH levels. For example, meat smoked with *birch twigs* was 10-fold higher than meat smoked with *birch logs*. Indeed, when combining *birch logs + twigs* for smoking, the meat [PAH4] increased enormously – 65-folds higher compared with *birch logs* smoking solely. In contrast, when smoking with various willow plant parts – logs, twigs and the combination – the [PAH4] did not differ notably (Table 4; Figure 9). Thus, the effect of plant part used for smoking, depend on the wood species. Despite this clear experimental finding, our analysis of herders' traditional smoked reindeer meat cuts illustrates that smoking with birch twigs may not necessarily result in high PAH contamination: compared to the meat smoked with *birch logs + twigs* in our *lávvu*-laboratory, the [PAH4] of traditional smoked meat with *birch logs + twigs & juniper* was nearly 10-times lower (Table 4).

Since twice as much BaP and total PAH in pork smoked with alder combined with juniper have been displayd compared to alder alone [35] , we expected the combination of smoking with *birch logs + twigs & juniper* to be higher than when smoking with *birch logs + twigs* alone. Instead, we did not find clear differences between the traditional herders' combination of *birch logs + twigs & juniper* and our solely *juniper* smoking. This may be explained by, a so far

unknown effect of this combination of different wood species and plant parts, but also differences in our experimental *lávvu*-laboratory smoking practice compared to the traditional smoking practice of Sámi reindeer herders. For example, Sámi herders' cool the smoke by adding water or having breaks in the process [24] – such measures were not used in our controlled *lávvu*-laboratory experiments. Our study underlines that all available knowledge – both traditional and scientific knowledge – is needed to evaluate the quality of smoked reindeer meat. Locally produced smoked reindeer products, using local wood species and Indigenous peoples' processes, might also accommodate Sámi traditional knowledge and family-based food products.

Smoke temperature peaks vs. smoke temperature means

Reindeer herders do not evaluate their smoked meat quality according to PAH contamination in their traditional knowledge system. They do, however, possess own techniques and justification of good meat quality in general [19], and hold traditional knowledge to evaluate their smoked reindeer product [24]. In contrast, scientists associate open fires with the generation of soot particles – consisting mostly of hydrocarbons and PAHs – as a result of incomplete combustion at high temperatures ~800–1 000°C [61]. Indirect smoking methods such as woodchips added hot air, rubbing wood against steel, or smoke flavouring [62] may consequently be considered healthier alternatives [12], compared to traditional method using open fires, such as *lávvu*-smoking.

However, our *lávvu*-laboratory shows that the mean glow temperature of *birch logs; birch twigs; willow logs; willow twigs; willow logs + twigs; juniper;* and *beech logs + chips* (Table 2) are all within what scientists define as the "best glow temperature" to secure low PAHs levels: 500–600°C [33]. Despite mean glow temperatures <600°C, meat and especially fat samples smoked with *birch twigs* had high PAH levels (15,8 and 127,3 µg/kg ww, respectively). Opposite, while mean glow temperature was >700°C when smoking with *birch logs w/o bark*, the smoked meat had low PAH contamination (3,2 µg/kg ww). Therefore, our study did not indicate a general correlation between high PAH contamination and high mean glow temperature.

Neither did we find direct correlation between high PAH contamination and high mean smoke temperature (Figure 9). For example, beech-smoking generated close to the highest mean smoke temperature, but the beech-smoked meat had the fare lowest [PAH4]. However, the wood species and plant parts with the highest [PAH4] (*birch twigs; birch logs+twigs; juniper*) were those that generated very high maximum smoke temperatures (Table 3

and Table 4), and several high smoke temperature peaks (Figure 5–8). Based on this, we suggest that high PAH content are not related to mean smoking temperature, but instead, likely a result of several high temperature peaks. PAH contamination have been displayed increasing with high smoke temperatures of 55–95℃ [63] . Correspondingly, in our *lávvu*-laboratory, those wood smokes with several high temperature peaks > ~55℃ resulted in the highest PAH levels (Table 4; Figure 5–8).

Herders' traditional knowledge is based on the appearance of the smoke and the meats. For example, smoking with juniper or birch twigs – not as much willow twigs – generate flying particles which deposits on the meat. Willow- and juniper-smoking, on the other hand, result in redder meat [24]. We observed similar colour-difference and particles deposition in our *lávvu*-laboratory controlled experiments (Figure 5, Figure 6 and Figure 7).

The intensity of the smoked product colour may be related to the time of smoking, the optical density of the smoke, the velocity and the smoke temperature [62] . We suggest that observed "flying ash", "white spots" and black particles on the meat might be soot particles, based on the higher PAH levels found in meat cuts with such depositions (juniper and birch). If so, herders' observations of particles could give an indication of the PAHs levels of their *lávvu*-smoked reindeer meat. Nevertheless, because not all particles are visible to the human eye and since traditional knowledge in its unique character have limitations when it comes to chemical analyses, controlled scientific studies are important when investigating PAH levels.

Bridging all available knowledges for food security

Bridging Indigenous knowledge system and science can lead to more equivalent, inclusive and useful outcomes Further, solutions to challenges in the Arctic are enhanced by a co-production of knowledge framework, including true open partnership and equity fairly provided space for all knowledge systems and holders [64]. Our study has been conducted in line with such co-production framework. Only after bridging reindeer herders' traditional, practical and holistic understanding with scientists' knowledge and controlled methodological set-up for temperature measurements and PAH chemical analysis, we will be able to evaluate the reindeer meat quality related to PAH and consequently make recommendations for Sámi food security.

In our study, a 'bridge is constructed" between Sámi traditional knowledge and science on reindeer meat smoking not only in the methodological design but also in the analyses of our findings. The fuzzy logic and holistic character of traditional knowledge [65] on one side, and the detailed deterministic analyses of temperatures and PAH chemistry on the other make this approach in the field of food security unique.

Despite lack of traditional smoked reindeer meat studies [4], many scientists have studied smoked food in general, e.g., [1,12, 14, 50, 63]. The lack of traditional knowledge in their experimental design might have affected their conclusions regarding traditional smoked products. Nevertheless, their studies indicate that firewood moisture, surrounding air humidity, distance from fire to meat cuts, amount of salt and relative amount of water in the meat, wood hardness related to harvest location, *lávvu* air flow and circulation technique and sequence of added firewood, and smoking time might also have affected the PAH content in the smoked meat investigated in our study.

Healthier alternatives to traditional smoking have been indicated [1, 13, 50]. For example, traditional smoking methods using smoking kiln results in higher PAH contamination than industrial processing using smoking chamber [50]. A study of traditional smoking by Native Americans in traditional tipi tents, similar to Sámi *lávvus* in their cone-shaped design, is highly comparative to our study [1]. Based on very high BaP levels [four sample <2 μg/kg ww and 36 samples >2 μg/kg ww; [1], the study suggests that high consumption rates of traditional smoked salmon over many years may elevate cancer risk. Compared to the BaP levels of indirect smoke house smoked lean reindeer meat displayed in an official Swedish control (<0.3 μg/kg; [13]), all our direct lávvu-smoked reindeer meat samples showed higher BaP content. Since smoke houses differ in size, the Swedish officials recommend PAH analysis of each individual practice, to find individual suitable solutions to reduce PAH [13] Due to the different smoking methods, wood and food products used in different traditional local practices, we support that it is important to study independent local traditions in case of PAH contamination.

For non-tobacco-smokers, food consumption are the major route of exposure to carcinogenic PAHs [30]. Gathering 9 714 PAH analyses, the EFSA found that median exposure across Europe varied between 1 168–2 068 ng/day (19.5–34.5 ng/kg b.w. per day). Average consumers are indicated to have low concern for human health – high consumers are indicated to have potential concern for human health [30]. Calculations based on our pilot study indicate that by, for example, eating 200 g reindeer meat smoked with *willow twigs + logs*, one may consume ~1 500 ng PAH4 – consumption similar to the average consumption per day. If eating 200 g reindeer meat smoked with *birch twigs + logs*, one may consume nearly 20 000 ng PAH4 – a very high consumption per day. Eating

reindeer fat, PAH4 consumption may be even higher. However, for example, do herders which smoke with birch, boil the smoked meat before eating it, to effect its palatability and tenderness [24]. We suggest that this may also affect the intake of PAH through consumption. Therefore, and because of the increased stomach cancer found among Sámi reindeer herders [25,26], it is important to be careful and conscious about what kind of smoked reindeer meat cuts one consume.

The most significant outcome of this study is, nevertheless, the importance of inclusive co-production between traditional knowledge and science to evaluate the traditional Sámi *lávvu*-smoking practices and products. Our innovative practical co-production approach to bridge traditional and scientific knowledge of smoking can act as a model for future bridging of knowledge in Arctic Indigenous Peoples' food security. Remaining studies include, for example, temperature measurements and related PAH analysis of traditional smoking by reindeer herders, air flow and humidity determination in the *lávvu*, maximum consumption levels of smoked reindeer meat, and PAH levels of boiled smoked reindeer meat.

Conclusion

By bridging scientific knowledge and traditional knowledge of smoking through the experimental *lávvu-laboratory* co-production method, we illustrated several examples of similarities between these knowledge spheres – despite their different ways of evaluating and justifying. Based on the correlations between scientific and traditional knowledge, we argue that reindeer herders not only may hold practical knowledge of e.g. what wood species and plant parts are used for smoking and how, but also hold a systematic knowledge of evaluating the temperature, and the appearance, quality, and colour of the smoke and the meat.

This pilot study is the first to display smoking temperatures and PAH levels of smoked reindeer meat cuts using a Sámi traditional smoking method. Previous studies of smoking in general have shown that PAH contamination of the smoked product depend on its fat content, casing type, the wood species used and the smoking temperatures. We revealed additional findings relevant to Arctic reality of food security, that PAH contamination of the smoked reindeer product depends on 1) the unique distribution of subcutaneous fat layer and the lean nature of reindeer meat, 2) the Arctic wood species and specific plant parts used for smoking, and 3) the presence of high smoke temperatures peaks caused by different firewood and fires.

Our unique methodological approach, bridging all available knowledge, indicate that specific recommendations relevant to traditional smoking practices are needed as a safeguard to human health. When it comes to Sámi *lávvu*-smoking of reindeer products, we recommend to 1) limit consumption of smoked subcutaneous reindeer fat; 2) use logs rather than twigs when smoking with birch, since it may contain much elevated PAH levels. If smoking only with willow, this precaution is not necessary; since it produces a white cold smoke and red meat with low PAH contamination and; 3) avoid high smoke temperature peaks and soot on the meat surface. Still some challenges connected to fully understand traditional knowledge remain – since this pilot study also discloses that reindeer herders may use practices that limit the PAH contamination.

Our co-production approach can be replicated in general future studies on traditional practices and in specific future studies on Sámi food safety and sovereignty, where Sámi traditional knowledge until now have been poorly recognised. Thus, this innovative co-production study may contribute both to safeguard human health and food security, and continuing traditional food smoking practice for future sustainability in Sápmi.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Consent

Written informed consent was obtained from participants.

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