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Response surface methodology analysis of rice starch and fructo-oligosaccharides as substitutes for phosphate and dextrose in whole muscle cooked hams

Virginia C. Resconi [a], Derek F. Keenan [a], Sophie Gough [a], Linda Doran [b], Paul Allen [a], Joe P. Kerry [c], Ruth M. Hamill [a, *]

[a] Teagasc, Food Research Centre Ashtown, Dublin 15, Ireland
[b] Teagasc, Food Research Centre Moorepark, Fermoy, Co. Cork, Ireland
[c] Department of Food and Nutritional Sciences, University College Cork, Cork, Ireland

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ABSTRACT

Rice starch (RS) and fructo-oligosaccharides (FOS) were studied as substitutes for phosphates (STPP) and dextrose (Dex) in cooked hams using response surface methodology (RSM). RS, STPP, Dex and FOS were combined in 25 runs and applied to *Biceps femoris* (BF) and *Semimembranosus* (SM) muscles. Muscles were injected (120% of green weight), tumbled, netted, and steam cooked. Cook loss and yield were affected by STPP. Colour was predominantly affected by muscle type, but also by the ingredients studied; whereas texture was principally affected by STPP and RS. NMR and expressible moisture data showed higher retention of free water in samples containing RS. This was visualized by light microscopy as starch gel pockets. Despite some reductions in yield, it is feasible to substitute STPP with RS and obtain a satisfactory quality product. However, higher levels of added FOS would be required to warrant a health claim.

1. Introduction

Processed meat products can contain significant amounts of added fat, salt and other additives. Therefore, they are excellent targets for reformulation from a health perspective. Furthermore, consumers are looking for more natural products, which also drives the effort by the meat industry to reduce the use of certain additives. However, many such ingredients perform important functional roles within processed meat products. One of these is inorganic phosphate, which enhances water retention, product juiciness and furthermore, reduces the need for added salt (Ruusunen, Niemistö, & Puolanne, 2002). Due to the functionality of phosphate, and its cost effectiveness, a strategy of partial rather than complete substitution of this ingredient is frequently pursued. Starches e.g. rice starch (RS) are an example of possible substitutes for phosphates, which may permit achievement of similar water retention levels and potentially further improve the texture and flavour of brined meat products (Joly & Anderstein, 2009).

Meat products also have great potential as vehicles for fortification with health-promoting ingredients. Medium-chain fructo-oligosaccharides (FOS) are now being tested in a variety of meat products e.g. sausage and mortadela (Archer, Johnson, Devereux, & Baxter, 2004; García, Cáceres, & Selgas, 2006; Keenan, Resconi, Kerry, & Hamill, 2014). FOS display excellent fat-substitution properties in meat products. For example, Cáceres, Garcıa, Toro, and Selgas (2004) showed that it is possible to manufacture mortadela with 40% reduced fat content, without sacrificing acceptable sensorial quality, by adding 12% added soluble short-chain FOS. FOS have also been tested as fat substitutes in dry and cooked fermented sausages (Salazar, García, & Selgas, 2009; dos Santos, Campagnol, Pacheco, & Pollonio, 2012). Whole muscle cooked ham products are already low in fat compared to comminuted meat products. Therefore, the addition of FOS as a source of fibre and to exert a possible prebiotic effect (Weiss, Gibis, Schuh, & Salminen, 2010) may be of greater interest in the cooked ham setting. Sugars or sweeteners [e.g dextrose (Dex), sucrose] are commonly added to curing brines, primarily to improve the flavour. Their action typically reduces the harshness of the salt, giving the cured product a smoother flavour (preventing 'over-warming'). Short

* Corresponding author.
E-mail address: ruth.hamill@teagasc.ie (R.M. Hamill).

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chain FOS are sweet-tasting (Coussement, 1999) and could theoretically be used in cooked ham to replace sugar. However, the effect of FOS on the technological quality of cooked ham is undetermined.

Response surface methodology (RSM) experiments permit modelling of the interactions between factors and mathematical models facilitate optimisation of product formulation for specified technological outcomes (Leardi, 2009; Myers & Montgomery, 2002). RSM has previously been used in research focused on formulation optimization, e.g. in whole muscle products such as injected pork and beef loins (Detienne & Wicker, 1999; Lowder et al., 2013). The aim of this study was to use an RSM approach to assess the performance of RS and FOS as substitutes for more traditionally used sodium tripolyphosphate (STPP) and dextrose in whole-muscle cooked hams and study the technological and physico-chemical properties of hams made with major pork muscles *Biceps femoris* (BF) and *Semimembranosus* (SM).

2. Materials and methods

2.1. Experimental designs

A d-optimal RSM experiment was designed using Design Expert (v. 7.6.1, Stat-Ease Inc., USA). Four numerical factors (ingredients) were included: RS (Remyline XS, Beneo, Belgium), STPP (Redbrook Ingredient Services Ltd., Ireland), Dex (Roquette Freres, Lestrem, France) and FOS (Beneo ORAFTI® Synergy1, Beneo, Belgium). Minimum and maximum levels (% w/w in injected muscle) for the ingredients were: 0 to 0.3 for STPP, 0 to 1.2 for RS, 0 to 0.2 for Dex and 0 to 3.0 for FOS. The following constraints applied to the design: RS + STPP $\geq$0.3; DES + FOS $\geq$0.2; RS + STPP + DES + FOS $\leq$3.3. In total, these conditions (maximum and minimum levels of the ingredients plus the constraints) generated an experimental design with 25 runs, with each run representing a different combination of the four ingredients, including 15 model points, five replicate points and five points to estimate lack of fit (Table 1). Each combination was applied to BF and SM muscles, with muscle type incorporated into the design as a categorical factor. Therefore, a total of 50 whole muscle hams (25 per muscle) were produced.

Table 1
Ingredient combinations according the response surface experimental design (d-optimal).[a]

Run	STPP	Rice starch	Dextrose	FOS
1	0.075	0.713	0.050	0.719
2	0.300	1.200	0.000	1.000
3	0.150	0.675	0.150	1.188
4	0.000	0.300	0.200	2.800
5	0.150	1.200	0.000	1.950
6	0.000	1.200	0.200	1.900
7	0.000	0.300	0.000	3.000
8	0.300	0.000	0.200	0.000
9	0.300	0.000	0.000	1.600
10	0.300	0.600	0.100	1.200
11	0.300	0.000	0.100	2.900
12	0.300	0.000	0.200	0.000
13	0.000	0.300	0.200	0.000
14	0.300	0.600	0.000	0.200
15	0.000	0.300	0.200	0.000
16	0.300	1.200	0.200	1.600
17	0.150	0.413	0.050	2.119
18	0.300	1.200	0.100	0.100
19	0.300	0.600	0.000	2.400
20	0.000	0.300	0.000	3.000
21	0.150	1.200	0.200	0.000
22	0.000	1.200	0.200	1.900
23	0.000	1.200	0.000	0.200
24	0.300	1.200	0.200	1.600
25	0.150	0.150	0.000	0.200

[a] Expressed by weight in the injected muscle. STPP: Sodium tripolyphosphates. FOS: Fructo-oligosaccharides.

2.2. Ham processing

The experiment was carried out in 25 sequential runs. Carcasses of 25 female pigs slaughtered under commercial conditions (Rosderra Irish Meats Group, Edenderry, Ireland) were selected for homogeneity in live weight (85–110 kg), age at slaughter (24–26 weeks), genetics (mainly Large White and Landrace backcrosses) and nutrition. Left legs were transported, 48 h after slaughter, to the pilot scale abattoir and meat processing facility at Teagasc Food Research Centre Ashtown. The experiment was spread over five weeks with four runs in each of the first four weeks and five runs in the last week (due to time constraints in product preparation and analyses). BF and SM muscles were excised, trimmed of excess fat and stored at ±2 °C. At 72 h post-slaughter, muscles were pumped to 120% of their green weight, using a 20-needle brine injector (Inject-O-MAT type PSM-21, Dorit Maschinen, Handels AG, Switzerland). Brines were prepared with levels of STPP, RS, Dex and FOS specified by the design. Brines also contained pickling salt (0.5–0.6% $NaNO_2$ and sodium chloride, ESCO - European salt company, Germany) and sodium ascorbate (Aland Nutraceutical Co. Ltd., China) at 2.5% and 0.05% by weight of the injected muscle, respectively. Muscles were tumbled (Dorit Vario-Vac VV-T-50, Dorit Food Processing Equipment Ltd., Switzerland) for 12 h intervals of 30 min work/rest periods at 6 rpm (2–4 °C). Tumbled muscles were netted, vacuum packed, heat shrink-wrapped and steam cooked (Jugema, MC 2500, Poland) (85 °C; 85% relative humidity) to a core temperature of 72 °C (~3 h). Hams were subsequently chilled (2–4 °C; 24 h) before being sub-sampled and vacuum packed for subsequent analyses [colour, TPA measurements (day 1), expressible moisture (day 2), water activity/composition (days 5 and 6) - for NMR and fructan analyses, samples were frozen on day 5 post-cooking at −20 °C until analysis]. Sampling location within the muscle and the size of the samples was kept consistent between analyses and treatments.

2.3. Weights and pH

pH (Thermo Orion Multimeter 250A, Orion Research Inc.) of brine, green muscle (72 h *post mortem*), and tumbled muscle was recorded in duplicate. Muscle weights were recorded at the green state and after injection, tumbling, netting, cooking and chilling from which % brine uptake, cook loss and total yield were calculated.

2.4. Composition and water activity

Two 20 mm thick samples were homogenised in a Robot Coupe (R101, Robot Coupe SA, France). Intramuscular fat and moisture concentrations of thawed minced samples were determined using the Smart System 5 microwave moisture drying oven and NMR Smart Trac rapid Fat Analyser (CEM Corporation USA) using AOAC Official Methods 985.14 & 985.26, 1990. Protein concentration was determined using a LECO FP328 (LECO Corp., MI, USA) Protein analyser based on the Dumas method and according to AOAC method 992.15, 1990. Salt (NaCl) was determined by titrating chloride ions in ashed (by furnace) samples with silver nitrite using the Mohr method (Kirk & Sawyer, 1991). Water activity was measured at ambient temperature with the Aqualab Lite meter (Decagon Devices Inc., Pullman, WA), according to manufacturer's instructions. Total fructan content was determined by modified AOAC (999.03) and AACC (32.32) methods using a Megazyme