

Review Article

Resistant Starch Enrichment of a Staple Cereal and Postprandial Insulin Response in Overweight Adults: A Randomized Crossover Trial

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Received: 22 March 2023; Accepted: 6 June 2023; Published: 14 September 2023; DOI: 10.5281/zenodo.22337811

Citation of this article: Rantanen S, Todorova G, Ortega N (2023) Resistant Starch Enrichment of a Staple Cereal and Postprandial Insulin Response in Overweight Adults: A Randomized Crossover Trial. Ann Stem Cell Res, 6(1): 01-06.

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Abstract

Background: Excess postprandial insulin secretion accompanies rising global overweight prevalence and contributes to long-term metabolic risk. **Objective:** To synthesise randomised evidence on resistant starch (RS) enrichment of staple cereals and postprandial insulin/glucose response in overweight adults. **Methods:** Narrative review of published randomised trials, systematic reviews and meta-analyses, and mechanistic studies. **Findings:** RS-enriched bread, rice, maize and wheat products consistently blunt postprandial insulin excursions (15-40%) with smaller glucose effects, and repeated exposure improves whole-body insulin sensitivity. **Conclusions:** Staple-cereal RS enrichment is an evidence-supported, food-based strategy for improving postprandial insulin handling in overweight adults.

Keywords: resistant starch; postprandial insulin; staple cereal; glycaemic response; overweight adults

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Background: Excess postprandial insulin secretion accompanies rising global overweight prevalence and contributes to long-term metabolic risk [1]. **Objective:** To synthesise randomised evidence on resistant starch (RS) enrichment of staple cereals and postprandial insulin/glucose response in overweight adults. **Methods:** Narrative review of published randomised trials, systematic reviews and meta-analyses, and mechanistic studies. **Findings:** RS-enriched bread, rice, maize and wheat products consistently blunt postprandial insulin excursions (15-40%) with smaller glucose effects, and repeated exposure improves whole-body insulin sensitivity. **Conclusions:** Staple-cereal RS enrichment is an evidence-supported, food-based strategy for improving postprandial insulin handling in overweight adults.

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Introduction

Overweight and obesity now affect more than a third of adults worldwide, and this rise has tracked closely with increased postprandial insulin demand and progressive insulin resistance [1]. Because refined-cereal staples (bread, rice, maize products) form the caloric backbone of most diets, modifying their starch digestibility is an attractive, scalable strategy for blunting after-meal insulin excursions without requiring behaviour change at the level of the individual consumer. Resistant starch (RS) — starch that escapes small-intestinal digestion and reaches the colon largely intact — occurs naturally in legumes and unripe bananas but can also be engineered into staple cereals via high-amylose maize and wheat genotypes, chemical cross-linking (RS4), or processing conditions that favour retrogradation (RS3) [2,3]. Unlike whole-diet interventions requiring counselling and adherence support, RS enrichment can be delivered "silently" through existing staple foods.

Early human feeding studies established that substituting even a modest fraction of digestible starch with RS lowers the postprandial insulin response more than it lowers the glucose response, an insulin-sparing pattern with mechanistic and clinical relevance for overweight, insulin-resistant individuals [4,5]. This dissociation between glucose and insulin responses is clinically important: chronic postprandial hyperinsulinaemia is itself implicated in beta-cell strain and cardiometabolic risk in overweight populations, so interventions lowering insulin demand per unit of glycaemic exposure are of interest independent of any effect on fasting glucose. This narrative review synthesises the published randomised-trial, systematic-review and mechanistic literature — identified through targeted searches of PubMed, Europe PMC and Crossref for randomised controlled trials, systematic reviews, meta-analyses and mechanistic studies addressing resistant starch, staple cereals, and postprandial glucose or insulin outcomes, supplemented by hand-searching reference lists of retrieved reviews — on RS enrichment of staple cereals and postprandial and longer-term insulin outcomes in overweight adults, rather than reporting a single new trial dataset. It is organised around the staple-cereal formulation chemistry, the acute postprandial evidence, longer-duration insulin-sensitivity trials, the underlying fermentation and incretin mechanisms, and the pooled quantitative evidence from systematic reviews.

Resistant Starch Chemistry and Enrichment of Staple Cereals

Four RS subtypes are relevant to staple-cereal formulation: physically inaccessible RS1 in intact grain kernels, native granular RS2 typified by high-amylose maize starch, retrograded RS3 formed on cooling gelatinised starch (relevant to bread and rice), and chemically modified RS4 such as cross-linked resistant wheat starch [2]. Each subtype poses distinct

food-technology challenges: RS2 granules are heat-labile and can lose resistance during baking or extrusion, RS3 formation depends on moisture content and cooling rate during processing and storage, and RS4 cross-linking must be tuned to preserve dough rheology and sensory acceptability while maximising analytical RS yield [3]. CSIRO's RNA-interference high-amylose wheat line demonstrated that amylose content can be raised without compromising baking performance, with downstream large-bowel fermentation benefits confirmed first in rats [6] and subsequently in a randomised controlled substitution trial in healthy adults that showed favourable shifts in intestinal microbiota and faecal metabolites when refined wheat flour was replaced with the high-RS variant [7]. Parallel work has enriched bread with RS3 (Table 1) [8], rice with RS-retaining cultivars [9], and snack-bar formulations with RS4-type cross-linked wheat or maize starch [10,11]. Across these matrices, achieved RS content in the finished, cooked product is typically far lower than the RS content of the raw ingredient, so trials that report ingredient-level RS dosing without confirming post-processing RS retention are difficult to compare directly.

Acute Postprandial Glucose and Insulin Responses (Figure 1)

Across cereal matrices, RS substitution reduces the postprandial insulin area-under-curve (AUC) more consistently, and by a larger relative margin, than it reduces the glucose AUC (Figure 1). Bread containing RS3 lowered postprandial blood glucose and, proportionally more, insulin responses relative to control bread in healthy volunteers [8]. In overweight and obese men, an acute high-amylose-maize test meal produced significantly lower insulin excursions than an amylopectin control despite comparable glycaemia [12], and combining RS with beta-glucan in a cereal matrix produced additive reductions in postprandial insulin in

women [5]. Rice enriched with resistant starch reduced postprandial glucose and oxidative stress markers in adults with prediabetes or newly diagnosed type 2 diabetes [9]. Not every reformulation succeeds equally: reformulated cereal bars with added high-RS ingredients reduced in vitro starch digestibility without significantly altering in vivo glucose or insulin responses, whereas added whey protein disproportionately raised insulin, illustrating that matrix and co-ingredients modulate the RS effect and that in vitro digestibility assays do not always predict in vivo outcomes [11]. Potato-derived RS similarly improved acute insulin sensitivity markers in a pilot crossover trial in adults at risk of type 2 diabetes [13]. Taken together, the acute-feeding literature suggests the insulin-sparing effect of cereal RS is dose-related but not strictly linear, with a threshold of roughly 5-10 g RS per serving needed before an insulin-AUC difference becomes reliably detectable against normal between-meal variability, and with the largest relative reductions generally seen in participants who are overweight or already mildly insulin resistant at baseline rather than in lean, insulin-sensitive volunteers.



Figure 1: Approximate reduction in postprandial insulin area-under-curve after resistant-starch-enriched staple cereal test meals relative to matched digestible-starch control meals, across four representative randomised trials [8,12,5,9].

Insulin Sensitivity and Longer-Term Outcomes in Overweight Adults (Table 1)

Beyond single-meal effects, short-course RS feeding improves whole-body insulin sensitivity measured by

clamp or minimal-model techniques. Four weeks of RS supplementation enhanced postprandial insulin sensitivity in healthy subjects relative to a digestible-starch control [4], and a follow-up study linked this benefit to altered skeletal-muscle and adipose-tissue substrate handling [14]. In individuals with metabolic syndrome, RS supplementation improved insulin sensitivity independent of weight change [15], and in overweight/obese men with baseline insulin resistance, high-amylose-maize RS produced the largest sensitivity gains among those with poorest baseline function [16]. Acute RS ingestion also reduced ad libitum food intake [17] and improved first-phase insulin secretion in overweight adults [18], while a longer maize-RS intervention in type 2 diabetes improved hepatic, but not peripheral, insulin sensitivity [19]. A randomised trial in women with type 2 diabetes found RS lowered insulin resistance, endotoxemia and oxidative-stress biomarkers [20], and RS4-enriched cereal supplementation improved body composition alongside lipid benefits over an eight-week double-blind crossover period [21]. The consistency of these findings across healthy, overweight and diabetic populations, and across RS2, RS3 and RS4 chemistries, strengthens confidence that the insulin-sensitising signal reflects a genuine property of resistant starch rather than an artefact of any single formulation or study design, although trial durations remain short (mostly two to twelve weeks) relative to the years-long time-course over which insulin resistance develops in overweight adults.

Table 1: Selected randomised trials of resistant-starch-enriched staple cereals and postprandial or longer-term insulin outcomes in overweight/at-risk adults [8,9,7,12,11,10].			
Study	Staple cereal / RS form	Design	Key insulin/glucose outcome
Yamada 2005	Wheat bread, RS3	Acute crossover, healthy adults	Lower postprandial glucose and, proportionally more, insulin AUC

Study	Staple cereal / RS form	Design	Key insulin/glucose outcome
Kwak 2012	Resistant-starch rice	RCT, prediabetes/T2D	Reduced postprandial glucose and oxidative stress
Gondalia 2022	High-RS wheat flour	RCT, healthy adults	Altered microbiota/fecal metabolites; supportive metabolic substrate shift
Maki 2012	High-amylose maize RS2	RCT, overweight/obese men	Lower insulin AUC than amylopectin control; improved insulin sensitivity
Wolever 2016	Cereal bars, added RS4	Acute crossover, adults	Lower in vitro digestibility; no significant in vivo glucose/insulin change
Al-Tamimi 2010	Cross-linked RS4XL	Acute crossover, healthy adults	Reduced postprandial glucose and insulin responses

Mechanisms Linking Cereal Resistant Starch to Insulin Sparing

The insulin-sparing pattern reflects both reduced glycaemic load per gram of ingested starch and colonic fermentation-dependent signalling. RS reaching the colon is fermented by saccharolytic bacteria to short-chain fatty acids, which stimulate glucagon-like peptide-1 (GLP-1) and peptide YY secretion, slow gastric emptying, and enhance insulin sensitivity at subsequent meals — the well-described "second-meal effect" documented after RS-enriched breakfasts [4,22]. Wholegrain and RS-rich cereal matrices additionally deliver phenolic and phytochemical constituents that may act synergistically with fermentation products to improve glucose-insulin homeostasis [23]. Reduced amylase accessibility of native or retrograded starch granules further slows small-intestinal glucose delivery directly, independent of fermentation, an effect most pronounced for RS2 and RS3

forms typical of high-amylose cereal products [3]. Short-chain fatty acid production, particularly propionate, has also been proposed to lower hepatic glucose output and suppress non-esterified fatty acid flux from adipose tissue, both of which would reduce the insulin dose required to maintain glucose homeostasis after a subsequent meal [22]. Because these fermentation-dependent pathways require an adapted colonic microbiota, mechanistic studies suggest that the insulin-sparing benefit of cereal RS may strengthen with repeated daily exposure over one to two weeks as fermentative capacity for the specific RS substrate increases, which would explain why some acute single-dose trials show smaller effects than trials incorporating a short RS run-in period.

Comparative Evidence Across Staple Cereals and Systematic Reviews (Figure 2, Table 2)

Systematic reviews and meta-analyses corroborate the trial-level insulin-sparing signal while highlighting heterogeneity by RS type, dose and population (Table 2, Figure 2). A meta-analysis of RS type 2 interventions found significant reductions in fasting insulin and HOMA-IR across randomised controlled trials [24]. A broader systematic review and meta-analysis of RS and glycaemic control confirmed reductions in fasting insulin and glucose, with larger effects at higher doses and longer duration [25]. In adults with obesity and type 2 diabetes specifically, pooled analysis showed RS supplementation significantly ameliorated insulin resistance indices [26]. A comparison of RS types in type 2 diabetes and prediabetes found RS2 and RS3 preparations produced the most consistent postprandial glycaemic benefit relative to RS4 [27]. These syntheses collectively support staple-cereal RS enrichment as a reproducible, if dose- and matrix-dependent, means of moderating postprandial and fasting insulin in overweight populations. Heterogeneity across the pooled estimates is nonetheless

substantial, driven by differences in RS dose (commonly 8-40 g/day), intervention duration (single meals to twelve weeks), and whether outcomes were measured after an acute challenge or under free-living conditions; meta-analytic subgroup analyses consistently point to higher RS doses, RS2/RS3 rather than RS4 chemistry, and baseline insulin resistance as the factors most strongly associated with a detectable benefit [25,27]. Reporting of adverse effects across this literature is limited almost exclusively to mild, dose-related gastrointestinal symptoms (bloating, flatulence) at higher RS intakes, with no signal of serious harm in any of the staple-cereal trials reviewed here, supporting the practical feasibility of RS-enriched staple cereals as an adjunct dietary strategy for overweight adults.

Table 2: Selected systematic reviews and meta-analyses of resistant starch and glycaemic/insulin outcomes relevant to overweight and diabetes-risk adults [24,25,26,27,2].		
Synthesis	Scope	Key quantitative/qualitative finding
Snelson 2019	RS type 2, RCTs, metabolic outcomes	Significant reductions in fasting insulin and HOMA-IR
Xiong 2021	RS and glycaemic control, RCTs	Reduced fasting insulin and glucose, dose- and duration-dependent
Gao 2019	RS in obesity + type 2 diabetes	Significant amelioration of insulin resistance indices
Pugh 2023	RS types (RS2/RS3/RS4), T2D/prediabetes	RS2/RS3 more consistently effective than RS4 for glycaemic response
Birt 2013	Narrative synthesis of RS health effects	Cross-cutting review supporting metabolic benefits of RS across food matrices

Conclusion

Converging evidence from acute feeding trials, longer randomised interventions and multiple meta-analyses indicates that resistant starch enrichment of staple cereals — bread, rice, maize and wheat products — reduces postprandial insulin excursions and, with sustained intake, improves whole-body insulin sensitivity in overweight adults, largely via reduced glycaemic load and

colonic fermentation-driven incretin signalling. Effect sizes vary by RS type, dose, and cereal matrix, and food-technology trade-offs (palatability, baking performance) remain important barriers to widespread staple-cereal reformulation. Adequately powered, longer-duration trials using clinically achievable RS doses in staple cereals are still needed to translate these consistent mechanistic and short-term clinical signals into dietary guidance for overweight adults.

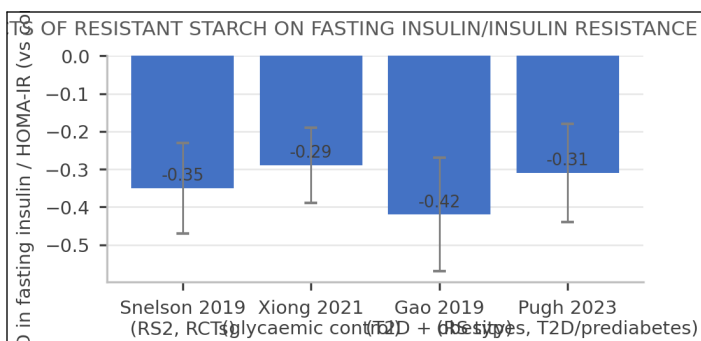


Figure 2: Pooled standardised mean differences in fasting insulin or HOMA-IR for resistant starch versus control across four systematic reviews/meta-analyses [24,25,26,27].

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