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Proceeding Paper

A Maternal Diet Enriched in Fiber and Polyphenols during Pregestation, Gestation, and Lactation Has an Intestinal Trophic Effect in Both the Dam and the Offspring †

Daniela Ceballos-Sánchez [1,2], Sergi Casanova-Crespo [1,2], Mara J. Rodríguez-Lagunas [1,2], Margarida Castell [1,2,3], Malen Massot-Cladera [1,2] and Francisco J. Pérez-Cano [1,2,*]

1 Physiology Section, Department of Biochemistry and Physiology, Faculty of Pharmacy and Food Science, University of Barcelona (UB), 08028 Barcelona, Spain; daniceballoss@ub.edu (D.C.-S.); sergi.casanova@ub.edu (S.C.-C.); mjrodriguez@ub.edu (M.J.R.-L.); margaridacastell@ub.edu (M.C.); malen.massot@ub.edu (M.M.-C.)
2 Nutrition and Food Safety Research Institute (INSA-UB), 08921 Santa Coloma de Gramenet, Spain
3 Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y la Nutrición (CIBEROBN), Instituto de Salud Carlos III, 28029 Madrid, Spain
* Correspondence: franciscoperez@ub.edu
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Abstract: Maternal diet during lactation, pregnancy or even before can influence the health of the baby. The Mediterranean diet is the one with the highest level of evidence due to its richness in fiber and polyphenols, among other bioactive components. This study investigated the impact of a diet rich in fiber and polyphenols (HFP diet) supplemented during pregestation, gestation, and lactation at the intestinal level in both dams and their offspring. This diet had an intestinal impact in both pregnant rats and their offspring in terms of intestinal growth. Further research is required to elucidate the underlying mechanisms involved.

Keywords: Mediterranean diet; maternal diet; fiber; polyphenols; gut

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1. Introduction

Current research indicates the vital role of a mother's dietary habits and nutritional well-being, not only during pregnancy but also before conception and throughout lactation, in the health of the fetus and infant, respectively [1]. Inadequate or excessive, as well as pre-pregnancy, weight conditions significantly influence various aspects of reproduction, including maternal and paternal fertility; conception; placental, embryonic, and fetal growth; and perinatal complications. These factors collectively contribute to suboptimal pregnancy outcomes for both the mother and the infant [2].

Additionally, nutrition during the first 1000 days of life (including pregnancy and the first two years when lactation is recommended by the World Health Organization (WHO)) [3] plays a pivotal role in a child's development. During this critical period, the baby's metabolic, immune, endocrine, and other developmental pathways mature concurrently with the establishment of symbiotic relationships with the microbiota [4].

The composition of the maternal diet is of importance, and a diet aligning with the Mediterranean Diet (MD), rich in fiber and polyphenols, among other components, seems to have a positive impact on both the mother's and the infant's health. However, this last aspect has been studied less. In addition, the specific period in which the dietary components can have their most significant impact on the fetus/infant still remains to be established [5].

Thus, the aim of the present research was to investigate the impact of a high-fiber and polyphenol-rich (HFP) diet, supplemented during pregestation, gestation, and lactation, on the body growth and the intestinal health of both dams and their offspring. Additionally, the study assesses its impact on plasma immunoglobulin concentrations.

2. Material and Methods

2.1. Animals

The study began with six-week-old female Wistar rats (n= 18) upon their arrival from Janvier Labs (Saint-Berthevin, France), which were housed in the experimental animal facility in the Diagonal-Campus of the Faculty of Pharmacy and Food Science (University of Barcelona, UB). The animals underwent a one-week acclimatization period before the start of the project. During the pregestation period, the rats were housed in pairs, and during gestation and lactation, they were individually housed. The animals were kept under controlled environmental conditions, which included humidity (50–55%), temperature (21 $\pm$ 2 °C), 12 h light/dark cycles, and *ad libitum* access to food and water. The procedures followed were approved by the Ethics Committee for Animal Experimentation of the University of Barcelona (Ref. 240/19) and the Generalitat de Catalunya (Ref. 10933).

2.2. Diets and Experimental Design

The animals were distributed into two groups: a control group (REF group, n = 9) that received the standard AIN-93G diet and another group (HFP group, n = 9) that received a high-fiber and polyphenol diet. This diet was formulated based on the fiber and polyphenol contents found in dietary profile of a gestating/lactating Spanish Mediterranean Cohort [6]. The 9-week study was divided into three periods, pregestation, gestation, and lactation, lasting 3 weeks each. After the pregestation phase, mating occurred for 4 days, resulting in 6 pregnant rats per group (n = 6/group). Some pups from each litter were euthanized on day 1 (n = 24/group), and later the litters were culled to 8 pups per mother. After the 3-week lactation period, mother rats and four pups per mother (n = 24/group), equally distributed by gender, were euthanized. Throughout these 9 weeks, weight, food intake, and water consumption were monitored three times a week, and feces were collected weekly.

2.3. Sampling

The following organs were weighted after euthanizing the animals at each time point: spleen, stomach, cecum, small intestine, liver, right kidney, thymus, heart, salivary glands (salivary G), and brain. In the case of the small intestine, measurements of length and width were taken.

2.4. Statistical Analysis

Student's *t*-test was used for statistical analysis. Significant differences were established at $p < 0.05$.

3. Results and Discussion

3.1. Effect of HFP Diet on Maternal and Offspring Organ Weights

The impact of the HFP diet on organ weight is presented in Figure 1. It can be observed that the maternal diet did not affect most of the organs in the mothers or the infants. However, significant differences were observed in the relative weights of the cecum and liver of the dams. Specifically, the HFP diet resulted in a notably higher relative weight of the cecum and a lower relative weight of the liver compared to the REF diet ($p < 0.05$). These or other changes were not observed in the pups from mothers receiving this diet on day 1, but, on day 21, the effect of the maternal diet on the cecum was evident ($p < 0.05$).

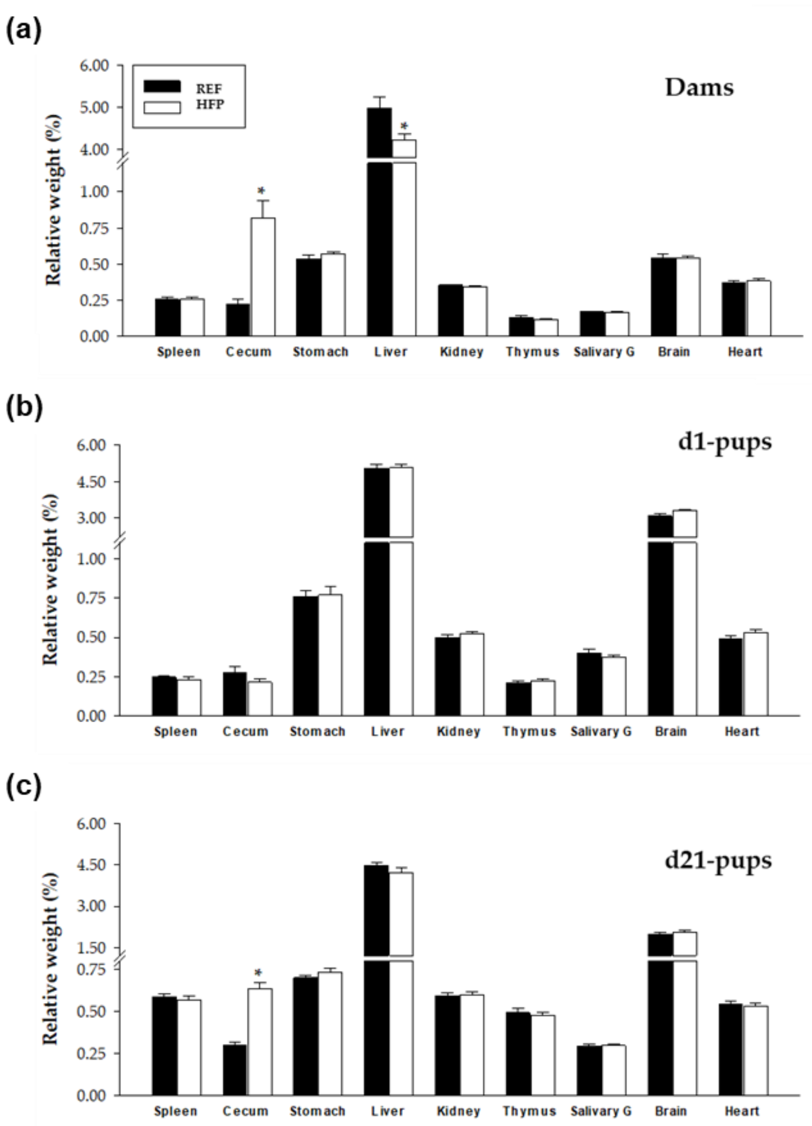

Figure 1. Relative organ weights (%) in high-fiber and polyphenol-rich group (HFP) and reference group (REF) for (**a**) dams; (**b**) d1-pups; and (**c**) d21-pups. Results are expressed as mean ± SEM of the g of organ per 100 g of body weight (n = 6/group for dams; n = 12/group in d1-pups; and n = 24/group in the d-21 rats). Statistical differences: * $p < 0.05$ vs. REF.

The cecum, which is the initial segment of the large intestine located between the ileocecal valve and the ascending colon, serves as a reservoir for fecal storage and is the primary site for the fermentation of soluble fiber. It is known that soluble fiber reaches the colon undigested because of its resistance to enzymatic degradation. It can then be metabolized by the gut microbiota, leading to the production of short-chain fatty acids (SCFAs). It is plausible to suggest that the fiber-derived SCFAs may induce the proliferation of beneficial bacteria such as bifidobacteria and lactobacilli, while inhibiting the growth of harmful bacteria. This fermentation process and the subsequent growth of beneficial bacteria could be the factors contributing to an increase in the cecal trophic effect and fecal mass production [7]. Additionally, the formation of viscous solutions due to soluble fiber combining with water may increase the volume of intestinal contents, potentially distending the walls of certain gastrointestinal tract structures.

3.2. Effect of HFP Diet on Maternal and Offspring Small Intestine

The small intestines of dams, d1-, and d21-pups were evaluated for weight, length, and width (Table 1). The weight of the intestine in dams and d1-pups was higher in the

HFP group than in the REF group ($p < 0.05$), although this difference was not observed on day 21.

Table 1. Relative weight of the small intestine (SI, %) and measurements of small intestine length (cm) and width (cm) at the end of the nutritional intervention for all experimental groups. Data are expressed as mean ± SEM (n = 6/group for dams; n = 12/group for d1-pups; and n = 24/group for the d-21 rats). Statistical differences: * $p < 0.05$ vs. REF.

	Dams		**d1-pups**		**d21-pups**	
	REF	**HFP**	**REF**	**HFP**	**REF**	**HFP**
SI weight (%)	3.31 ± 0.08	4.03 ± 0.11 *	3.11 ± 0.11	3.23 ± 0.07 *	3.40 ± 0.06	3.78 ± 0.09
Length (cm)	88.54 ± 5.26	86.20 ± 4.98	17.82 ± 0.49	19.53 ± 0.42 *	43.78 ± 1.54	52.65 ± 2.94 *
Width (cm)	1.04 ± 0.05	1.18 ± 0.12	n.e. [1]	n.e.	0.53 ± 0.01	0.60 ± 0.06

[1] n.e.: non-evaluated.

In addition, the maternal HFP diet also influenced the length of the small intestine in the offspring at both 1 and 21 days of life compared to the REF group ($p < 0.05$). This trophic effect is unlikely to be related to the direct intake of fiber or polyphenols. Instead, it may result from intrauterine epigenetic changes, the impact of the diet on maternal milk composition or microbiota, or a combination of these factors [8,9]. Future studies will evaluate the mechanisms involved to gain a better understanding of these results.

4. Conclusions

In conclusion, a diet rich in fiber and polyphenols appears to have an intestinal impact in both pregnant rats and their offspring. However, further research is required to elucidate the underlying mechanisms of these effects and their potential implications for maternal and neonatal health.

Author Contributions: D.C.-S., S.C.-C., M.M.-C., M.C., M.J.R.-L. and F.J.P.-C. were involved in the design and/or execution of the experiments. D.C.-S., S.C.-C., M.M.-C. and F.J.P.-C. analyzed and interpreted the results and drafted the paper. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The animal study protocol was approved by the Institutional Ethics Committee of the University of Barcelona (protocol code 240/19 approved on 11 March 2020.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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