

Enrichment of sweet bakery products with pulse flours

Ángela Bravo-Núñez, Manuel Gómez*

Food Technology Area. College of Agricultural Engineering. University of Valladolid, 34071 Palencia, Spain.

*Corresponding author e-mail: pallares@iaf.uva.es

Abstract

Legumes are rich in protein, fiber, and minerals. Several studies have shown the health benefits of their consumption. For these reasons, interest in the use of legume flour in bakery products has grown in recent years. However, legumes have strong off-flavors that prevent their use in high percentages. Sweet flavors are able to mask these off-flavors, and thus sweet bakery products such as biscuits and cakes seem to be suitable items for enrichment with legume flours. In this review, we address the influence of the incorporation of legume flours in these products based on the incorporation percentages and flour characteristics, especially the protein content and particle size, as well as possible treatments to reduce the off-flavors. The effects of enrichment with legume protein concentrates or isolates, the use of these to replace eggs in cakes, and the potential of aquafaba (cooking liquid of legumes) are also addressed.

Keywords: cookies, cakes, legume, bean, chickpea, lentil, lupin

1. Introduction

Pulses are part of the leguminous family (any plants that grow in pods) and present a high protein content, much superior to that of cereals^[1]. For this reason, they have been known as the “meat of the poor”, and the interest of science and food industry in pulses has greatly increased in recent years. This interest in pulses has been led by the tendency to eliminate or drastically reduce meat consumption, for various reasons^[2] as well as the fact that 2016 was declared the International Year of Pulses by the FAO (Food and Agriculture Organization of the United Nations) to acknowledge the significant contribution of legumes in feeding the world^[3]. In addition, environmental sustainability is a key factor for transitioning to more plant-based diets^[4]. For a diet to be considered sustainable, it has to contribute to the good nutritional status and long-term health of an individual and the community while having a low environmental impact^[5]. Legumes can provide high-quality proteins with a reduced ecological footprint compared to animal-based foods. However, to significantly increase the consumption of vegetal proteins, their acceptability should be enhanced^[6].

In addition to chickpeas, beans, lentils, peas, cowpeas, and lupines, other leguminous plants such as soy and peanuts, which present a high fat content, are mainly used for animal feed. In this review, we only focus on the first group.

The main advantages of pulses constitute their high protein, fiber, and mineral content as well as the presence of bioactive compounds^[1]. There is evidence suggesting that pulse consumption is conducive to good health, as it seems to reduce the risk of cancer^[7], high cholesterol levels in blood, or cardiovascular diseases^[8]. In addition, the amino acid composition of pulse proteins is complementary to that of cereals, in part due to their high lysine content, which makes their combined consumption beneficial^[9], especially in those diets deficient in proteins. In addition, pulse starches/flours have lower digestibility than those of cereals^[10,11]. In fact, pulses can be regarded as foods with a low glycemic index (GI)^[12], due to the changes that occur during cooking and the subsequent retrogradation of pulse starches. This is a nutritional advantage for diabetics as well as for healthy individuals^[13], and the inclusion of pulse flours can be used to reduce the GI of bakery products. Nonetheless, pulse consumption also presents drawbacks, such as the presence of anti-nutritional factors^[14] or off-flavors^[15]. In general, the presence of these anti-nutritional factors in pulses has been limited by genetic improvement in the current varieties. In addition, their negative effects get drastically reduced after boiling/hydrothermal treatments.

These treatments, together with sprouting or fermentation, have been proposed to reduce the off-flavors of pulse flours.

Table 1. Production of the main pulses by continent (Millions of tons)

	Bean	Chickpea	Cowpea	Lentil	Lupin	Pea
Africa	6,94	0,73	6,97	0,24	0,07	0,63
America	8,07	1,39	0,07	2,51	0,06	4,55
Asia	14,61	13,23	0,16	2,99	-	2,78
Europe	0,78	0,85	0,03	0,33	0,34	5,25
Oceania	0,03	1	-	0,26	0,71	0,34
World	30,43	17,19	7,23	6,33	1,19	13,53

FAO^[122]

The cultivation of pulses is distributed around the world, with local particularities. As shown in Table 1, Asia is the principal producer of pulses, with more than 75% of chickpea crops, and almost 50% of the ones of bean and lentil crops. For their part, lupine crops are concentrated in Oceania (60% of the world production) and cowpea in Africa (96% of the world production). Pea crops extend mostly between Europe and America and are cultivated to a lesser extent in Asia. Of all the pulses, the production volume of beans stands out, followed by chickpeas and peas. By countries (Table 2), India is the main producer of chickpeas and beans and the second highest producer of lentils, while Canada is the main producer of lentils and peas. As crops are distributed all around the world, there are pulses than can be used in bakery products in every continent.

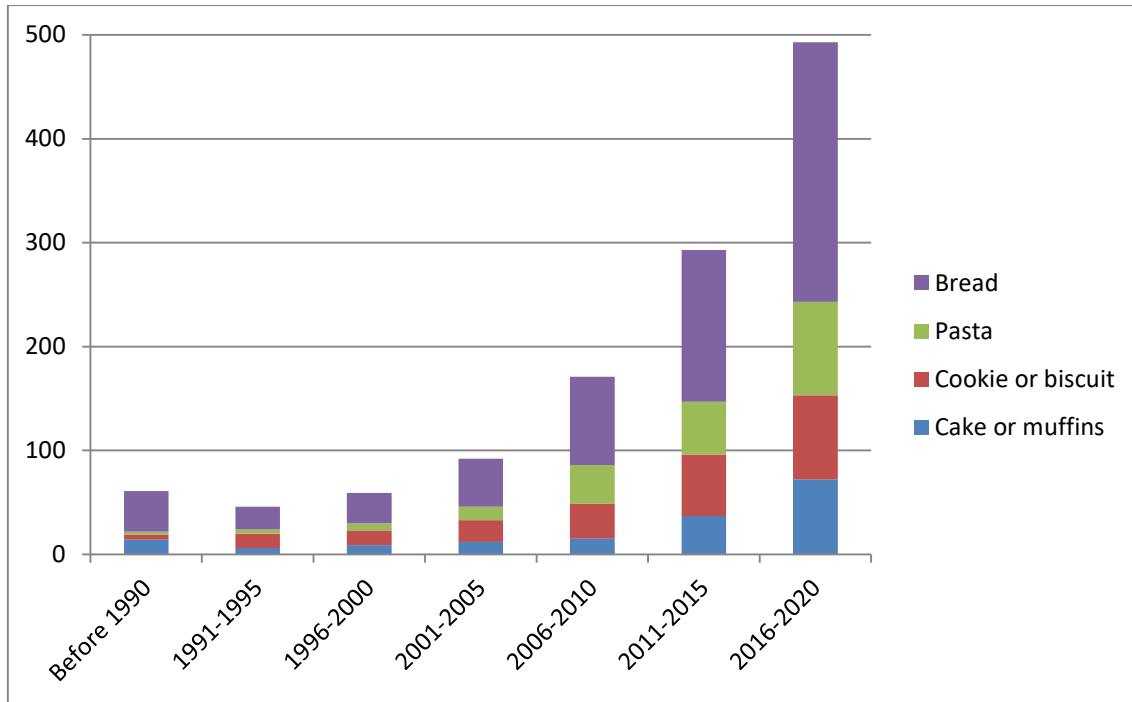
Table 2. Major pulse producing countries (Millions of tons)

Bean	Chickpea	Cowpea	Lentil	Lupin	Pea
India 6.22	India 11.38	Nigeria 2.61	Canada 2.09	Australia 0.71	Canada 3.58
Myanmar 4.78	Australia 1	Niger 2.38	India 1.62	Russia 0.14	Russia 2.30
Brazil 2.92	Turkey 0.63	B. Faso 0.63	USA 0.38	Poland 0.12	China 1.50
USA 1.70	Russia 0.62	Burundi 0.39	Turkey 0.35		India 0.92
China 1.34	USA 0.58	Ghana 0.22	Australia 0.26		Ukraine 0.78
Tanzania 1.21	Myanmar 0.51	Tanzania 0.20	Nepal 0.25		USA 0.72
México 1.20	Ethiopia 0.51		Ethiopia 0.17		France 0.62

FAO^[122]

For the abovementioned reasons, food industry and scientists have been interested for several years in the study of pulse flour use in bakery products, snacks, baby foods, and meat analogous or sport foods^[16]. In bakery products, these flours can be used either alone or mixed with cereal flours. As Figure 1 shows, research on this topic has increased exponentially during the last 5 years. In addition, it can be appreciated that these studies mainly focus on the usage of pulse flours for bread making, both in wheat and in gluten-free breads. The multiplicity of articles on this topic has generated comprehensive reviews in recent times, among which the one by Sozer et al.^[17] about the potential uses of pulse flours, Bresciani and Marti's^[18] review that focused on bakery products in general, Melini et al.^[19] and Foschia et al.'s^[20] reviews dedicated to gluten-free products, and the review by Boukid et al.^[21] focusing on wheat breads stand out. For its part, the inclusion of pulse flours for pasta elaboration has been reviewed by Mercier et al.^[22]. Monnet et al.'s^[23] review of the interaction between the components of flours from pulses and cereals and their influence on the generated products (snacks, pasta, biscuits, cakes, and bread) is also significant. There are also more specific reviews about the incorporation of certain pulse flours in breads, such as chickpea^[24] or lupine^[25] flours. However, the incorporation of pulse flours in sweet bakery products, such as cookies and cakes, and their benefits have received less attention, and only some of them are named in broad reviews that are more focused on other types of products. The incorporation of pulse flours in cakes and cookies is easier than in breads. These products do not develop a gluten-network (when elaborated with wheat flour)—as this network is not essential to achieve a product with good characteristics—and, therefore, it is possible to completely substitute wheat flour with a pulse flour. Hence, it is relatively easy to achieve quality gluten-free products, and if pulse flours do not want to be used alone, they can be combined with starches or other gluten-free flours. The presence of other ingredients, in particular sugar and aromatic ingredients but also fat or oil, helps hide the off-flavors of pulse flours, reducing the acceptability problems of bakery products containing these flours. Nevertheless, it has to be taken into account that the presence of these ingredients decreases the nutritional quality of the resulting products, which conflicts with the nutritional benefits of using legume flour.

Figure 1. Articles on the use of pulses in various cereal products



Research carried out on Web of Science (Food Science and Technology) on 21 April 2020 “Pulses, or chickpea, or lentil, or bean, or pea, or cowpea or lupin, and name of the product”

The aim of this review is to take a retrospective look at the available information on the incorporation of pulse flours in sweet bakery products (cookies and cakes) and the possible strategies to improve their quality for optimal application.

2. Cookies

Research on incorporating pulse flours in cookies has been performed for several decades, becoming widespread in the 1980s. One of the first such studies revealed that the effects of pulse flours are dependent on the used pulse^[26]. The results of this study showed that defatted soybean flour reduced the spread ratio, while peanut and field pea flour (*Vigna unguiculata*) barely modified it, with replacements of up to 30% of wheat flour. The experiment also indicated that although all the pulses reduced the sensory evaluation of taste and texture, peanut did so to a lesser extent. These differences could not be attributed to the different composition of pulse flours, as soybean and peanut flours have a far more similar composition to each other than to field pea. Moreover, the study results suggested that the spread ratio reduction triggered by the presence of pulse flour can be compensated by a higher addition of water. At about that time, Cady et al.^[27]

managed to replace 25% of the wheat flour in an oatmeal cookie—a formula containing less weight of wheat flour—with navy bean flour without reducing its acceptability. A decrease in acceptability was already observed at substitution levels of 35%, but no other aspects were evaluated. This shows that the results depend on the type of cookie, its components, and the weight of the flour in the formula, since in other studies the loss of sensory quality was evident from lower percentages. In fact, De Penna et al.^[28] observed a reduction in acceptability when including 20% or more of sweet lupine flour. Hoojjat and Zabik^[29] had earlier observed that the substitution of wheat flour with navy bean flour in sugar snap cookies—by up to 30%—reduced the spread ratio, and although this did not negatively affect texture, it significantly reduced flavor perception. These results were confirmed by the observations of McWatters^[26] and Hegazy and Faheid^[30], who studied the replacement of wheat flour by up to 15 % with soybean, lupine, or chickpea flour. In their study, DeFouw et al.^[31] substituted up to 30% of wheat flour by navy bean hulls in sugar snap cookies. Following the trend of other studies that had also studied navy bean flours, spread ratio and sensory evaluation (especially flavor) were reduced. However, the authors observed that roasting the hulls at high temperatures reduced the negative effect on the flavor and texture. The positive effect of roasting on the organoleptic quality of cookies with pulse flours (by partial substitution of wheat flour) was also confirmed for other pulses^[32,33]. In Patel and Rao's^[33] study, as well as in the one by Sathe et al.^[34], the reduction of the spread ratio was already starting to be correlated to the greater water retention capacity of these flours (in these cases the alkaline water retention capacity). Patel and Rao^[33] also observed that pulse germination can increase flavor perception and generate harder and more compact cookies; however, germination decreased texture perception in their study, likely because of its negative effect on the spread ratio. Obeidat et al.^[35] observed similar results with sprouted lupine flours. In their research, although sprouted flours were not compared with a non-sprouted flour, a significant reduction was observed in the spread ratio with the incorporation of the sprouted flours, but acceptability only decreased from percentages of substitution of 40%, higher than what was observed in other studies. Spread ratio reduction in this study seems to be more influenced by the high protein content of pulse flours than by germination. It is known that germination reduces the water holding capacity (WHC) of flours^[36], which has been demonstrated to increase the spread ratio of cookies^[37]. The fact that this was not observed by Obeidat et al.^[35] can be related to a minimal effect of germination on WHC, as germination times were short (up to 24 h). Nevertheless, when comparing different

germination times, the spread ratio was higher with higher germination time. The reductive effects of sprouting on dough rheology parameters, and therefore on the increase in the spread ratio, can be correlated to a higher enzymatic activity of sprouted flours, especially of hydrolytic enzymes such as amylases or proteases^[38]. As for the improvement in the flavor perception observed by Obeidat et al.^[35] after the inclusion of germinated pulse flours, it can be correlated with starch dextrinization and sugar generation, due to the higher content in amylases, but this effect will depend on the processing and resting times of the dough.

Articles published in the 21st century tend to be more comprehensive, with wider analysis and deeper discussion. The earliest studies in the 21st century confirm what previous research had pointed out, such as the reduction of spread ratio and increase in the protein content of cookies with the incorporation of pulse flours (chickpea or broad bean) and a modification in color that depends on the used pulse^[39]. The authors also stated that small additions (below 12%) did not worsen the overall acceptability of cookies. For cookies with high pulse flour content, Ai et al.^[40] studied the influence of particle size and bean variety on cookies made from mixtures of bean flour (70%) and corn starch. These authors observed that cookies made with coarser flours had higher spread ratio values and resistant starch content than cookies made with finer flours, but in both cases the resistant starch and slowly digestible starch (SDS) content were higher than those of wheat cookies. The lower digestibility of coarse flours has already been reported in studies with different cereals^[41,42], and has been attributed to the difficulty of enzymes in penetrating these particles. Roman et al.^[42] also found that particles with a more compact structure, such as those coming from the hard parts of the corn endosperm, were also less digestible, which may explain the lower digestibility of cookies with pulse flours, as these are harder than wheat. It is because of this hardness that the milling of pulses becomes more complex and can lead to a higher degree of damaged starch if fine flours are to be obtained, so it is essential to control these parameters in preparation of the various pulse flours^[43]. The effect of particle size on the spread ratio of pulse flour enriched cookies observed by Ai et al.^[40] aligns with the observations of Belorio et al.^[44] regarding maize flours. But, as observed by Belorio et al.^[44], a minimum percentage of fine flours is necessary to give cohesiveness to the dough and allow it to be worked without breaking. Ai et al.^[40] also observed a negative correlation between WHC and spread ratio of pulse-flour-enriched cookies, regardless of particle size. This effect may explain the lower spread ratio of cookies made with legume flours as observed in previous works, due to the increase in WHC with pulse proteins

when mixed with starches or flours^[45] and the high protein content of pulse flours. In fact, in the case of cookies made from wheat flour a positive correlation of protein content and WHC, that results in cookies with a lower spread ratio, is also known^[37]. Ai et al.'s^[40] results were confirmed in a similar study by Cappa et al.^[46], wherein it was observed that a reduction in the particle size of different bean flours resulted in reduced hardness and fracture strength in addition to an increased spread ratio. The same effect of particle size on spread ratio and hardness was observed by Zucco et al.^[47] when comparing different pulses. In this study, it was also observed that pulses with a higher protein content—which, as mentioned, have a higher WHC—generated more compact and harder cookies. Another contribution of this study on the nutritional aspects is the increase of the antioxidant power of the cookies by raising the content of pulse flour in the formulation, an effect that does not depend on the particle size but on the pulse used. It should also be taken into consideration that the effect of pulse flours on the spread factor and hardness of the cookies will also depend on the flour with which they are mixed^[48], as these flours may differ in particle size, protein content, and water absorption capacity. Similarly, a pulse flour may worsen the organoleptic quality of wheat cookies but may improve that of cookies made with other flours, although with less acceptability.

One way to improve the acceptability of cookies with pulse flour can be the removal of the bran of pulse flours, as the incorporation of lupine bran yielded cookies with lower acceptability than those with only lupine flours^[49]. In this study, apart from verifying the higher protein and minerals content of cookies with pulse flours, the authors proposed the use of xylanases to increase the spread ratio of cookies and decrease their hardness, thus minimizing the negative effects of the incorporation of pulses.

Regarding the heat treatment of flours, Simons and Hall^[50] proposed boiling pinto beans and drying before obtaining the flour to improve the organoleptic profile of the cookies. Nevertheless, they did not find significant differences between the organoleptic profile of cookies made with raw, boiled or sprouted pinto bean flours, which contradicted the observations of previous studies. These differences may relate to the level of substitution (40%) with respect to the original flour mix (mixture of oat, rice, tapioca, and quinoa flours). Sarabhai et al.^[51] also suggested the use of flours obtained from puffed chickpeas and had suffered heat treatment to achieve this puffiness. However, the results of this study were not positive—spread ratio and hardness increased, reducing the flour's acceptability when compared to amaranth flours. An effect similar to that of

boiling (hydrothermal treatment) can be achieved with extrusion; in fact, Bassinello et al.^[52] and Siddiq et al.^[53] proposed using extruded bean flours for cookie elaboration. In Siddiq et al.'s^[53] research, organoleptic perception was improved when comparing cookies elaborated with extruded flours and boiled flours. De la Rosa-Millán et al.^[54] also tried enrichment with extruded flours from sprouted pulses (black bean) in nixtamalized blue maize cookies, achieving an increase in the protein and fiber content and a reduction in the predicted glycemic index. In general, these studies observed similar results when compared to those that studied unextruded pulse flours, decreasing spread ratio and organoleptic profile when pulse flour content was high. Nevertheless, further research is needed on this matter, as these studies did not compare the extruded flours with unextruded flours or with controls without pulse flours in some cases, and extrusion conditions were also not studied. It is known that extrusion conditions, such as temperature and humidity, influence starch gelatinization to a great extent^[55,56], which influences the water absorption of the flours, which in turn can change the spread ratio and hardness of cookies.

Although most of the studies about the incorporation of pulse flours considered different types of beans, there are also some studies with other local pulses. In this way, in Africa—where cowpea is common, and where among cereals sorgo stands out—the enrichment of whole-grain sorgo flours with cowpea flour has been proposed for cookie elaboration^[57]. The effects on the organoleptic profile were influenced by the type of sorgo (white or red), but in all cases the addition of cowpea flour resulted in an increase in protein digestibility, and the final cookies presented higher protein and fiber than the commercial standard. Regarding lentil flour, it has been shown making use of downgraded lentils yields results that are very similar to those of premium lentil flours^[58]. Inclusion of lentil flour resulted in an increase in protein and fiber content, as well as the antioxidant capacity. Lentil flour incorporation also resulted in darker and slightly harder cookies, but in contrast to the results of other works spread ratio was higher. This may be due to the high weight of the flour in the formula (lower sugar and fat content than in other studies), which may facilitate the formation of the gluten network in cookies with wheat flour^[37], which in turn would reduce expansion during baking.

It must be borne in mind that most of the studies used a sugar snap cookie formula, having a high sugar content. Nonetheless, pulse flours can be incorporated in salty cookies, such as crackers. In these types of cookies, the weight of flour in the formulation is much higher, which, together with

the higher water content makes it possible for gluten network to be formed^[59]. Hence, in these cases the effect of pulse flours can be different. In fact, Millar et al.^[60] observed that the addition of broad-bean (*Vicia faba*) or pea (*Pisum sativum*) flours at 40% levels reduced the specific volume and height of cookies (due to lower gas retention), which resulted in a higher spread ratio, probably due to the effect of reduced gluten content. Regarding the nutritional aspects, results were similar to those observed for other cookie types, with an increase in protein, fiber, phenolic substances, and antioxidant capacity in cookies with pulse flours. In this research, Millar et al.^[60] proposed a reduction of baking time for cookies with pulse flours due to their effect on cookie color, although these color changes depended on the type of pulse used, something also observed in other studies. To minimize the negative effect of the substitution of wheat flour on the gluten network, Benkadri et al.^[61] suggested incorporating xanthan gum into mixtures of rice and chickpea flours. Xanthan gum has been commonly used as a substitute for gluten in the elaboration of gluten-free breads^[62], and in this case increased the farinographic absorption, G' and G'' values of the dough, specific volume of obtained cookies, and their organoleptic acceptance, reducing the hardness.

From a nutritional point of view, on top of protein and fiber enrichment, and the improved antioxidant capacity that pulse flours provide to the cookies, it has also been demonstrated that enrichment of oat cookies with pulse flours decreased serum glucose levels and increased insulin levels in diabetic rats, reducing the hyperglycemic peak in healthy rats. It also has a greater hypolipidemic effect than commercial oat cookies^[63]. Thus, the incorporation of bean flour seems to have cardioprotective potential.

In addition to pulse flours, other products obtained from the milling process of pulses, such as protein isolates or concentrates, hulls, or extracts of the hulls, can also be used. However, studies on this subject are limited. In the case of proteins, some studies have proposed the incorporation of pea protein isolates—in percentages of 0–30%—in different formulations or mixed with different flours or starches^[45,64,65]. In general, these products achieve greater protein enrichment but do not provide fiber or other components of nutritional interest. These studies showed that protein increased the water absorption capacity of flours, and therefore the G' and G'' values of the dough, but it barely changed the spread ratio or hardness of gluten-free cookies, for up to 30% of substitution. In fact, cookies with 30% of pea protein can be achieved, which triples the protein content of the cookies without changing the acceptability compared to the control. Mota, Lima,

Ferreira and Raymundo^[66] evaluated the effect of 10% of lupin protein on cookies made from different flours. These authors observed that the presence of lupin boosted the cookie area (except for cookies elaborated with rice flour) and the hardness (except for the cookies elaborated with Kamut flour). No sensory evaluation was performed. Unfortunately, there are no studies with protein concentrates obtained by micronization and separation by cyclones, nor with the starch-rich fraction obtained in this process.

Regarding the use of pulse hulls, there are no studies beyond the ones by DeFouw et al.^[31] and Bilgiçli and Levent^[49], where a lower acceptability of lupine bran cookies versus lupine flours was observed. Chávez-Santoscoy et al.^[67] proposed the inclusion of up to 7% of a black bean (*Phaseolus vulgaris*) seed coat extract in cookies from nixtamalized flour. With these levels, a considerable enrichment of flavonoids, saponins, and anthocyanins was achieved without modifying the spread ratio or the texture of the cookies, but they were slightly darkened with the highest levels. However, both the nutritional composition of the hulls and their organoleptic characteristics were very different from those of the flours of the endosperm.

The use of a bean paste (pureed beans) as a substitute for sugar in oatmeal cookies^[68] and cooking water of soybeans as an emulsifier in gluten-free crackers^[69] has also been proposed. According to Serventi et al.^[69], soybean cooking water has a high proportion of saponins and high foaming and emulsifying power, but its incorporation into cookies facilitates the absorption of water during storage, which is a negative factor as it softens the cookies with time. These products may have greater application in the preparation of cakes, where foaming capacity can be important.

Another point that needs further investigation is the effect of the incorporation of pulse flour on the acrylamide formed during the baking process of cookies. In fact, while Miskiewicz et al.^[70] claimed that replacing wheat flour with chickpea flour reduced acrylamide in cookies, which they attributed to the lower concentration of reducing sugars, Palermo et al.^[71] observed an increase in acrylamide in cookies with okara. Okara is the residue from the production of tofu or soybean or chickpea-based vegetable milks and is high in protein and fiber^[72]. These authors attributed the high acrylamide content to the high absorption capacity of the fiber present in okara, which reduces water activity and affects the Maillard reactions. This explanation would be compatible with the reduction of acrylamide in cakes with pulse flour from the endosperm, where the fiber content is lower; however, further research is needed.

3. Cakes

Gluten network is not essential for the elaboration of cakes, as it is in the majority of cookie types, and the gluten network does not develop in the majority of these products due to the negligible mechanical work to which the batter is exposed during mixing (batters are actually liquid and show no resistance to this mixing) as well as the high amount of sugar and fat in the recipes. Flour plays a structural role in these, and, in contrast to what happens in cookies, starch gelatinizes in cakes during baking with a sufficient amount of water and the right temperature. This phenomenon is essential since it enables the batter to retain the gas formed by the baking powder and influences the final texture of the cakes^[73].

Studies on the incorporation of pulse flours in cakes are more recent than those on cookies, and most of them are after 2010. As gluten does not play a major role, it is possible to make cakes with only legume flours, but the incorporation of these flours can have a negative effect on the final quality of the product, so many of the studies have only replaced a percentage of wheat flour or other gluten-free flours with legume flours. As occurs with cookies, in general, the partial replacement of the original flour or starch by a legume flour generates cakes with a higher protein and mineral content^[74], with a slight increase in the fat content and a lower estimated glycemic index. However, it must not be forgotten that these values as well as the quality of the cakes are influenced by the used pulse flour^[75,76], even with low substitution of the original flour^[77]. One of the first studies about the incorporation of pulse flour in cakes was by Gómez et al.^[78]. This study analyzed the influence of different chickpea varieties, together with the presence of chickpea hull, on the quality of sponge cakes. Flours that contained the hulls had a lower protein content and a higher fiber content than the chickpea flours which did not. The addition of pulse flour reduced the volume of cakes and increased their hardness, both in sponge and in layer cakes. The sponge cakes with whole chickpea flour were harder, but this factor only had a significant influence on the sponge cakes. The chickpea variety also had a significant influence on the volume of both types of sponge cake and on the texture of the layer cake. The use of chickpea flours with lower protein content resulted in cakes with a greater volume, which may indicate that a minimum starch content is necessary to achieve a good cake volume, but it is also possible that there is an influence of the particle size of the flours, and thereby the hardness of the pulses—something not studied in this work. In fact, the influence of particle size on the volume and texture of cakes has already been demonstrated in other works with wheat flours^[79,80] and with gluten-free flours, such as rice

flours^[81]. The effect of particle size of pulse flours on cakes was confirmed in the study by De la Hera et al.^[82] with lentil flour, where a decrease in volume and increase in hardness of the cakes after partially replacing wheat flour with lentil flour was confirmed. In this study, it was observed that coarser flours generated cakes with a lower specific volume and higher hardness, regardless of the fact that the batter had a lower density and therefore a greater incorporation of air. However, it was observed that the batter obtained with coarse flours had larger bubbles and a more heterogeneous distribution, something that was also reported in other works^[81,83], and this is likely to be the driving force favoring coalescence and gas loss during baking. However, particle size cannot explain the differences in batter and cakes made with wheat flour (with a particle size similar to the fine flour used), which confirms that an excess of protein, or a lack of starch can be detrimental for the quality of the cakes. In both works an influence of the pulse variety on the final color of the cakes was also observed^[78,82].

To test the effect of particle size and protein content, Gomez et al.^[84] studied the effect of substituting wheat flour with micronized pea flour, and with the fractions resulting from the following separation of the micronized pea flour (a fraction with more than 50% of protein, thin fraction, and another one with around 10%, thick fraction). All these flours were finer than the wheat flour. In this work, it was not possible to obtain cakes elaborated only with the pea flour rich in proteins with a minimum quality, mainly because of the low expansion of the batter, although with lower proportions the incorporation of this fraction gave place to cakes with good volume, particularly in sponge cakes. Nevertheless, cakes made with 100% micronized flour or flour fraction with lower protein content showed a specific volume very similar to that of wheat cakes, with regard to both sponge and layer formulations. This confirms the problem of an excessive protein content, and the importance of particle size. In fact, it was proven that the bubble distribution of the batter with a 50% fraction of any of the pea flours was similar to that obtained with only wheat flour, and in the case of the batter where the used flour was the micronized pea flour or the pea flour fraction rich in proteins (the thin fraction), bubble distribution was even better. In the case of layer cakes, the substitution of wheat flour with thin pea flour (rich in protein) increased cake hardness and reduced cohesiveness, but for sponge cakes this effect was less noticeable and in fact cakes with the high-starch fraction (thick fraction) presented a similar hardness to that of the wheat cake. It has to be considered that while sponge cakes are elaborated with a foam-based batter, layer cakes are made with an emulsion-based batter, and that the

functionality of the ingredients differs in some aspects between the two batter types^[73,85]. Moreover, although flour functionality is similar for both kinds of batter, particle size can have a greater influence in one cake than in another^[81]. Nevertheless, the main inconvenience of the incorporation of these flours is their effect on the acceptability, which decreases, particularly in layer cakes, where the decrease in acceptability was quite evident even with substitutions of 25%. In sponge cakes this effect was slightly lower, even at percentages of substitution of 50%, but it has also to be pointed out that control sponge cakes (made with wheat flour) had a worse acceptability than layer control cake, probably due to their dryness (they have no fat), as they are usually consumed together with a cream, filling or a coating. In this study, both cakes were of the low ratio type (sugar content lower than flour content). It has to be considered that sugar and some other ingredients can help to mask the off-flavors of pulse flours, so in high-ratio cakes or in formulations with aromatic ingredients, the negative effects of pulse flours can be minimized^[15]. In fact, the addition of strawberry flavor to gels made with faba bean protein isolates was effective in reducing dried pea flavor^[86]. The reduction of off-flavors in such products should be studied in greater depth.

The effect of protein content and particle size has also been studied by Singh et al. ^[87] in cakes elaborated with pea flours. These authors observed that while the effects on rheology parameters were evident, with higher G' values for the flours with higher protein content and coarse particle size, the effects on volume and texture were not that clear due to interactions between the two factors (protein content and particle size). The differences observed with other articles may be due to the presence of particles with larger sizes in this study (up to 425 microns) that can generate a sandy feeling in the final cake. This could also be due to the fact that the beans were hydrated for 16 hours and then dried before milling, unlike other studies that involved directly milling the legumes, which could change the characteristics of the obtained flours^[88].

In conclusion, it is possible to obtain cakes with good volume and texture by replacing wheat flour with pulse flours, even up to 100%, as Ruan et al. ^[89] also found in chiffon cakes with mug bean flour, although the batter obtained usually has higher viscosity^[75,90]. But to obtain cakes with the best quality, both the protein content and the particle size are important ^[84]. Therefore, the variety and growing conditions influence the quality of the flours obtained to make cakes. This, together with the differences between the various types of cake, may partly explain the contradictions observed between some studies. It should also be borne in mind that legume flours modify the

dielectric properties of batter^[91], which must be taken into account when cakes are cooked by using microwaves. However, the main problem with the incorporation of pulses is the lesser acceptability of these cakes, mainly because of the strange flavors they provide. Therefore, it is important to investigate how to reduce this negative effect.

Treatments that have proven effective in lowering the off-flavors of legume flours include heat treatments, fermentation, and germination^[15]. Although the whole batter is already slightly heat-treated during baking, hydrothermal treatments of legumes or flours have been proposed to improve the organoleptic quality of cakes or similar products. In this way, English et al. ^[88] proposed moistening and drying pulses before milling, to improve the acceptability of chocolate brownies. This product contains chocolate and a high proportion of sugar, which can help mask the strange flavors of legumes, and there is no significant difference between the acceptability of brownies made with wheat flour and those made with mixtures of up to 50% pulse flours. However, brownies made 100% out of legume flours showed significantly reduced acceptability, mainly due to the lower aroma and flavor assessment. Nevertheless, no significant differences were detected between flours from moistened or un-moistened pulses, suggesting that this treatment does not seem effective in improving the organoleptic quality of cakes elaborated with pulse flours.

If, in addition to moistening the pulses, they are precooked, the flavor of these flours can be modified to a greater extent, but starch would also be gelatinized at the same time, changing the properties of the flour. For instance, Chompoorat et al. ^[92] studied the effect of flours made from pre-cooked (boiled) beans on cupcakes, and found an evident effect of cooking on the rheology of the smoothies (increasing G' and G''), very possibly due to the effect of the pre-gelatinization of starch, which increases the water absorption and the thickening capacity of these flours^[55,56,93]. These authors observed that there was an increase in the organoleptic quality of the cupcakes when increasing the pre-cooking time, but surprisingly, despite the effect of heat treatment on the rheology, no significant differences were observed in the height or texture of the cupcakes obtained. Unfortunately, no specific volume data are given (only height), or any images of the products, nor is there a control made with wheat flour, so it is not possible to compare these results with those of other articles. In fact, Gomes et al.^[94], who also studied the effect of a heat-treated bean flour in gluten-free cakes, in this case by extrusion, observed a clear decrease in the specific volume and an increase of hardness of the cakes made from extruded bean flour content in

comparison with the control wheat cake. Nevertheless, this is misleading, as gluten-free cakes containing extruded bean flour should have been compared with a gluten-free cake control. Regarding sensorial analysis, gluten-free cakes containing extruded bean flour showed a worse organoleptic profile than the control with wheat flour, but neither the gluten-free control (without legume flour) nor similar products elaborated with unextruded bean flour were evaluated. Therefore, with the available results, it is not possible to conclude whether heat treatment of pulse flours is beneficial for the quality of cakes elaborated with pulse flours. Due to the limited amount of research on hydrothermal treatments of legumes and the contradictory results of these studies in terms of specific volume and hardness, further studies are necessary to draw definitive conclusions. It should also be taken into account the effects on the rheology of the cakes may be compensated by the addition of more liquids (e.g., milk or water) due to their high water absorption capacity. In addition, pre-gelatinized pulse flours may even be used to reduce the oil content of cake batter, as already proposed with wheat flours by Román et al.^[95].

The effect of sprouting pulses upon their incorporation in cakes or muffins has scarcely been studied. Rumiya et al.^[96] analyzed the effect of the incorporation of sprouted lupin flours (7 days), but without a comparison as to the effect of the incorporation of un-germinated lupin flours, and moreover the incorporation percentages were low (8% maximum). The muffins obtained had lower height and darker color than the control, but no significant differences were observed in respect of hardness, although an increase in cohesiveness was observed. These results may be related to the degradation of the components of the sprouted flour, especially starch and protein. However, the most noticeable effect was the higher content of phytosterols and total phenols, and higher antioxidant capacity of the muffins that contained the sprouted pulse flours. The increase of the antioxidant capacity of flours after sprouting has already been observed in several studies and has been associated with both the accumulation of vitamin E and polyphenols in sprouts^[38]. Kaczmarzka et al.^[97] observed that sprouting or fermentation of pulse flours significantly changed the taste of muffins with lupin flour. These changes were attributed to protein degradation, the consequent increase in free amino acids, and their consequences on Maillard reactions. To date, however, the impact of sprouting or fermentation on the acceptability of cakes elaborated with these flours has not been analyzed. In any case, it is necessary to conduct further studies that compare pulse flours with and without germination, and with different germination conditions, as well as clarify their effects on the quality and acceptability of the cakes.

The use of hydrocolloids, such as xanthan gum, or egg whites has also been proposed to improve the quality of cakes made from legume flours, although without clear results. However, the use of these products is common in the production of commercial gluten-free muffins^[98]. In this way, it is known that the incorporation of xanthan gum is capable of improving the volume of gluten-free cakes and increases the products' shelf life due to its higher water absorption capacity ^[99,100]. Andrade et al.^[101] proposed the inclusion of xanthan gum in sponge cakes made with fava beans flour and observed an increase of viscosity and incorporation of air in the batter, but they did not observe a significant effect on the specific volume or acceptability of the cakes. However, it did modify the texture, increasing hardness and cohesiveness. In a similar study, but with muffins made of chickpea flour, Herranz et al.^[102] confirmed the increase of rheological values (G' and G'') with the incorporation of xanthan gum, but observed a lower incorporation of air, although distributed in the form of small bubbles, which generated an increase in the final volume. In this study, the sensory panel perceived that the presence of xanthan gum in cakes resulted in greater sponginess and moisture, and they were easier to swallow, possibly because of the water-holding capacity of the xanthan gum and the lower loss of moisture during the baking process. Discrepancies between the results of Andrade et al.^[101] and Herranz et al.^[102] indicate that the effect of xanthan gum depends on the cake formulation used. Alvarez et al.^[103] experimented with an increase of the egg white content in muffins, but they did not observe any effect either on the specific volume or acceptability of cakes elaborated with chickpea flour, which showed lower specific volume and acceptability than cakes elaborated with wheat flour. Nevertheless, egg white increased the hardness of cakes, possibly because of the coagulation of the ovoproteins during baking^[85], but did not improve the cohesiveness of the cakes. It should be noted that in this study there is no large increase in the amount of egg white, since the authors only replaced the yolk content of the eggs with an equivalent amount of egg white. This minimal effect is proven by the small changes in the rheological properties of the batter, which depend on the starchy material used in the cake^[104]. In contrast, the replacement of gluten-free flour by high doses of egg white has been associated with a lower density of the batter, due to its foaming capacity, and a higher specific volume of the cakes but with a much harder and more cohesive texture^[105]. Another use of legumes in the preparation of cakes is orientated to significantly increase their protein content by substituting part of the flour by protein isolates, usually from peas, although derivatives from other pulses have also been tested. In some cases, the use of these isolates has

been proposed in combination with other products such as transglutaminase and xanthan gum to improve the quality of the cakes, although with irregular results^[106]. As mentioned earlier in this review, a minimum starch content is required to produce cakes, which limits the percentage of flour that can be substituted with a protein isolate. For this reason, the available studies only replaced up to 45% of the flour with pulse proteins isolates. Matos et al.^[107] demonstrated that it is possible to incorporate soy protein up to almost 20g/100g rice flour, without modifying the volume or texture of the muffins, although the color of the crumb was slightly dark and G' and G'' values of the batter increased. Bustillos et al.^[108], who incorporated pea protein isolates, observed an increase in the G' and G'' values, as well as in viscosity of sponge cakes batter, which they attributed to the higher water absorption capacity of pea protein. However, contrary to the results of Matos et al.^[107], these authors observed a decrease in the amount of air entrapped in the batter, which they attributed to the low foaming capacity of pea proteins compared to other proteins. Nevertheless, this effect was more marked when substitution of the wheat flour was higher than 30%. This, together with the fact that Bustillos et al.'s^[108] research involved substituting flour with pea protein, explains the results of Matos et al.'s^[107] study, wherein protein was added on top of the flour (no substitution). In fact, Sahagún et al.^[105], in a study of gluten free layer cakes where rice flour was substituted with up to 45% of pea protein, confirmed the results of Bustillos et al.^[108], as they reported an increase of batter viscosity, which these authors related with a higher water absorption capacity. Sahagún et al.^[105] also observed a decrease in the specific volume and an increase of hardness of the cakes, that was higher with higher pea protein content, but only significant when rice flour was substituted with at least 30% of pea protein. Contrary to what was observed by Bustillos et al.^[108], in this study a significant increase of density was not observed, which can be due to the lower density of the batter of layer cakes compared to sponge cake batter^[81,83], and to the different role of proteins as stabilizers in the different cake types^[73,85]. What Sahagún et al.^[105] did observe was a darker color of the cakes with pea protein, and a lower acceptability when protein content was 30% or more, mainly due to the low scores in odor and taste. In this sense, and to avoid this effect, Bravo-Núñez et al.^[109] advise the use of protein mixtures for flour substitution, to obtain cakes with high protein content (45%). These authors were able to substitute 45% of rice flour by a mixture of proteins that contained 66% pea protein, with the other 33% of the mixture being composed of whey and egg white proteins, and generate cakes with a specific volume and hardness similar to the control, and increased acceptability

relative to cakes with only pea protein. Bravo-Núñez et al. ^[109] also concluded that this acceptability can be improved by slightly increasing whey protein content in the protein mixture, as this protein improves flavor and odor of the cakes.

In the case of protein isolates, on top of the protein content, which is usually above 80%, the protein origin must also be taken into consideration, as protein isolates from different pulses can have different properties that will affect the quality of the cakes. In fact, there are flavor differences among these isolates, and different off-flavors were perceived by consumers^[110]. These differences were also reported by Shevkani and Singh^[111], who enriched cakes elaborated with maize starch using 10% of protein isolates of kidney bean, field pea, and amaranth. All the proteins increased G' and G'' values of the batter in a similar way, but these authors reported differences in respect of the color, volume, and texture of the cakes. According to Shevkani et al.^[112], these differences occur even among different varieties, as they observed that two protein isolates from different cowpea varieties (red and white) with similar protein content not only had different colors but also showed different foaming and emulsifying properties as well as different water and oil retention capacities. These differences influenced batter rheological properties as well as the specific volume and texture of the final cakes. The protein isolate with better foaming and emulsifying properties resulted in cakes with a better specific volume than the control, while the other isolate generated muffins with a lower volume. Pulse proteins have also been used to try to substitute egg in cake formulations. Nevertheless, the substitution of egg protein by pea protein results in batter with higher viscosity and density, and cakes with a lower specific volume, higher hardness and darker color^[113]. However, these authors achieved batter with the same density as the control, and minimized the negative effect of legume proteins on the specific volume of the cakes when incorporating them into the cakes, together with the pulse protein, xanthan gum, and an emulsifier (soya lecithin), in line with the results of Arozarena et al. ^[114] using lupin protein. This proves that the role of the ovoproteins in air retention cannot be achieved only by pulse proteins. All cakes with no egg showed lower springiness than the control, which could be related to the way in which egg protein coagulates during baking and its effect on texture. Another way of improving the functionality of pea proteins as egg replacers involves modifying their hydrophobicity using acylating agents^[115]. The effect of this modification will depend on the used agents, and although they improve foaming properties, this improvement is only at neutral or acidic pH. Still, the effect of these modified pea proteins as egg replacements gives worse results

than the use of blends of unmodified pea proteins and soy lecithin, and the cakes obtained with the modified pea proteins still have lower specific volume and higher hardness than the control. Campbell et al. ^[116] proposed thermal denaturalization of both unmodified and glycosylated cowpea protein isolates as egg replacers, but with substitution below 40% of the egg content. They observed that heat treatment reduced protein solubility and increased cake acceptability, although cakes with a specific volume and acceptability similar to the control were only obtained with egg substitution of 20% by glycosylated cowpea protein isolate. Substitution of 40% showed in all the cases specific volumes lower than the control and lower acceptability, in line with the observations of other studies. When analyzing the performance of pulse proteins as egg replacements, it must not be forgotten that the functionality of egg proteins varies with the type of cake. In foam-based cakes (such as sponge or angel cakes), where batter incorporates higher amounts of air, the foaming capacity of egg is more important than in emulsion-based cakes (layer and pound cakes or muffins), which have higher content of oils/fats^[73,85]. In fact, substitution of egg by pulse proteins gives better results in the emulsion-based cakes than in foam-based cakes. Along these lines, Jarpa-Parra et al. ^[117] developed egg-free muffins with lentil proteins with a height similar to the control muffin and with a sensory evaluation similar or even better than the control muffin. The observed results in this same study with angel cakes were different, as the use of lentil protein as egg replacer worsened the organoleptic results even when the egg substitution was partial. In both cases (muffins and angel cakes) the absence of egg resulted in a lower percentage of air cells and harder texture than the controls. Another legume product that has been used to replace eggs in cake making is wastewater from chickpea canning, also known as aquafaba^[118]. Aquafaba is a liquid rich in proteins and saponins and with good foaming and emulsifying properties that has been proposed as a substitute for egg white^[119]. These authors showed that aquafaba has similar properties to those of ovoproteins, and they developed an egg-less cake with a texture similar to the control, although the volume was slightly lower and the internal structure was different. Unfortunately, this work did not analyze the sensory acceptance of the cakes, which would have been interesting because of the possible off-flavor that aquafaba could engender in the cakes. In general, both biscuits and cakes show a significant reduction in product acceptability when legume flours are incorporated. This reduction seems to be associated with a lower appreciation of their aroma and taste. Although it is difficult to compare the results of different studies, it seems that this reduction in acceptability is greater for cakes than for cookies. Clark and Johnson ^[120]

compared the inclusion of lupin kernel fiber in different products, such as bread, pasta, juices, muffins, and breakfast bars. It is not possible to draw any significant conclusions as the level of fiber incorporation was different in each case, being much lower in bread and pasta (by flour content), and the smallest changes in acceptability were noted. This was because the authors wanted to achieve a similar increase in the percentage of fiber. Nevertheless, the reduction in acceptability, associated with changes in taste, was somewhat greater for muffins than for bars (more like cookies), but the percentage of fiber in the total formulation was higher for bars. In a later work Hall and Johnson^[121] performed a similar analysis but with the addition of sweet lupin flour. In this case muffins with a 60% substitution of wheat flour by lupin flour (17% lupin flour over total ingredients) suffered a greater loss of acceptability than chocolate chips with 50% substitution of wheat flour by legume flour (10% of total). In general, studies comparing similar amounts are necessary to draw stronger conclusions, but there is a clear influence on the product into which the legume flour is incorporated as well as a clear influence of the type of legume or legume derivative incorporated in reducing the acceptability of these types of products.

4. Conclusions and future direction

In view of the work carried out to date, we can conclude that it is possible to make cookies and cakes with legume flours, either on their own or mixed with other flours or starches. The additions provide a clear nutritional improvement to these products, mainly an increase in the protein, mineral, and antioxidant content. However, the incorporation of leguminous flours modifies the characteristics of these products, and in general this incorporation reduces the spread ratio of the cookies and the volume of the cakes while also increasing their hardness and generating darker products. However, these changes can be minimized by selection of the appropriate pulse source and the characteristics of the flours, such as their particle size, making it possible to achieve products that are very similar in appearance and texture to the original ones. The aspect that still constitutes a major barrier towards the commercialization of these products is the reduction in acceptability after the incorporation of legume flours due to changes in taste and aroma. Although the use of germination or heat treatment of flours has been proposed, these treatments modify the characteristics of the dough and the final product without a significant impact on their acceptability. More studies need to be conducted to improve the acceptability of cookies and cakes made from legume flours, either by modifying the flours, formulations, or production processes of the products in which pulse flours are incorporated. In this sense, the inclusion of ingredients

with a marked flavor, such as chocolate, can help mask the strange flavor of the legumes. Further studies should always try to consider sensory evaluation to obtain more robust conclusions regarding acceptability.

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Declaration of interest

The authors have no conflict of interest.

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