Lupin Flours as Additives: Dough Mixing, Breadmaking, Emulsifying, and Foaming

N. J. Pollard,[1,2,3] F. L. Stoddard,[2,4,6] Y. Popineau,[5] C. W. Wrigley,[1,6,7,8] and F. MacRitchie[1,9]

ABSTRACT

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The nutritional quality of various food products could be improved by supplementation with grain legumes to increase protein content and to improve the balance of essential amino acids. The lupin grain is a good candidate for this role, given its yield potential in a range of climatic environments and soil types. To establish the practicality of extending the use of lupins as food additives, the functional properties of various species and cultivars of lupin were studied for their effect as additives to baked products and their ability to provide foaming and emulsifying properties. Of the two lupin species that are commonly cultivated commercially, *Lupinus albus* showed the greater potential as a bread additive; loaf height and structure were maintained when lupin flour was substituted for wheat flour at levels up to 5%. This level of substitution offered the advantage of reducing mixing time. The detrimental effects at higher substitution levels appeared to be associated with the nonprotein components of the lupin flour. *L. albus* showed better functionality than *L. angustifolius* in emulsifying attributes, although *L. angustifolius* showed greater potential as a foaming agent. Defatting the lupin flour may be necessary to show these properties to best advantage. Certain cultivars (within each species) showed preferable performance, indicating the potential for plant breeding to provide germplasm better suited to uses as food additives.

Lupin (*Lupinus* spp.) is a leguminous crop that is well adapted to a range of climatic and soil types. In Australia, 1.6 million tonnes of lupin seed are produced annually, representing 80% of the total world production. Internationally, the main use of the lupin seed is for human consumption, although it has been used as a stock feed within Australia, where its market value is subject to the volatility of alternative sources of feedstuffs. Lupins also have a considerable potential to supplement human nutrition. The identification of such roles will provide growers with significant market niches. The two main species grown in Australia are *Lupinus angustifolius* and *L. albus*. Cultivars chosen for the present study have all been selected for low levels of alkaloids, thus providing an intrinsic advantage over soy protein as a food additive.

The nutritional quality of wheat protein is lower than that of proteins from pulses and oilseeds due to its low levels of lysine, methionine, and threonine (Kulp 1988). Nevertheless, demand for wheat-based bakery products is increasing, particularly in developing countries where the major grain is wheat (Quail 1996). The nutritional quality of these products could be improved by supplementation with nonwheat proteins such as those from pulses, including lupins, which would increase the protein content and improve the essential amino acid balance of the baked product. In this respect, lupins might be seen as fulfilling a role similar to that of soybean in North America (Lui 1997). Lupins offer several potential advantages over soybeans. In particular, the digestibility of lupin protein and oil is superior to that of soybean. Lupins have a lower content of trypsin inhibitors, which can interfere with digestive processes, and less phytic acid, which binds minerals such as calcium and zinc to reduce their bioavailability. Lupins have lower levels of saponins and lectins, which can act as gastric irritants. The higher dietary fiber content of lupins is typically associated with cholesterol-lowering activity.

For lupin flour or proteins to achieve a market as a breadmaking additive, it is important to establish that dough mixing properties are not adversely affected. The information obtained about rheological properties at dough mixing and extension will help predict the final quality of the bread. Breads made from composite flours, incorporating significant nonwheat grain, are subject to the same breadmaking process as wheat. Dervas et al (1999) reported that lupin flour can replace wheat flour up to 5%, although if defatted and concentrated, the replacement level increased to 10%. Similarly, Lucisano and Pompei (1981) reported that lupin flour (*L. albus* cv. Multolupa) could be substituted for up to 10% without detrimental effects on loaf parameters. However, these studies were limited in the range of lupin species and cultivars examined. They neglected the likelihood that some lupin genotypes would be better suited for such uses than others. The aim of this study was to extend the examination to baking properties of two major species of lupin, and also to include a wide range of cultivars of commercial relevance.

Furthermore, foaming ability and emulsification are valuable properties for many food products. An understanding of the contribution of lupin flour to these properties would expand the potential use of lupin flours as nutritional additives. For example, the presence of gas cells in the continuous liquid dough makes the dough comparable to foam (Eliasson and Larsson 1993). Gas cell stability is important for baking behavior and bread quality. It is determined by the surface-active components, proteins and polar lipids, present in the flour. As both proteins and lipids are present in the dough, it is relevant to study the behavior and interactions of these components at gas-liquid interfaces. By studying the interfacial behavior of proteins and lipids at an air-water interface, it is possible to detect molecular interaction between the components. In addition to the possible role of lupin products as foaming agents in baking systems, a major objective of this study was the more general use of lupin products as food ingredients for situations requiring added foaming capability and foam stabilization, such as the replacement of egg albumin.

Food emulsions (oil-in-water and water-in-oil) are thermodynamically unstable and will rapidly separate into two phases unless a surfactant is present at the interface. The kinetic stability of an emulsion thus depends on the physical and chemical properties of the adsorbed surfactant layer and its ability to prevent flocculation and coalescence of droplets of the dispersed phase. Because proteins are amphiphilic and able to form cohesive viscoelastic films at these interfaces, they are preferred over low molecular weight surfactants as emulsifiers in food applications. King et al (1985) showed that a lupin-protein isolate was comparable to soy-protein isolates in emulsion-forming ability. Emulsion studies on a range of lupin cultivars had not been reported at the time of this work.

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[1] CSIRO Plant Industry, North Ryde, NSW 1670 Australia.
[2] Plant Breeding Institute, University of Sydney, NSW 2006 Australia.
[3] Present address: N. J. Hehir, Goodman Fielder Research, Summer Hill, NSW 2130 Australia. E-mail: naomi.hehir@gfmb.com.au.
[4] Present address: Biosciences Division, School of Applied Sciences, University of Wolverhampton, Wulfruna St., Wolverhampton WV1 1SB, UK.
[5] INRA UBTP, BP 71627, 44316 Nantes Cedex 3, France.
[6] Quality Wheat CRC, Locked Bag No. 1345, North Ryde, NSW 1670, Australia.
[7] Food Science Australia, PO Box 52, North Ryde NSW 1670, Australia.
[8] Corresponding author. Phone: +61 2 9490 8401. Fax: +61 2 9490 8499. E-mail: colin.wrigley@csiro.au.
[9] Kansas State University, Department of Grain Science, Manhattan KS 66506-2201.

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This article describes an investigation aimed at determining aspects of functionality among species and cultivars of lupin and certain protein components. The resulting information should provide a basis for renewed efforts in extending the utilization of lupins for human food. The results also provide a basis for breeders to improve lupin grain quality for processing as food additives.

MATERIALS AND METHODS

Materials

Ten cultivars of *L. albus* and four of *L. angustifolius* obtained from Agriculture Western Australia were used in these experiments (Table I). The flours were prepared by splitting the lupin grain into two cotyledons and a hull using a barley pearler (Strong-Scott). The splits were separated from the hulls by running through a separator (Carter Dockage Tester, Minneapolis, MN). The splits were further cleaned from the hulls by a fan, and finally by hand. The cleaned splits were ground using a Falling Number mill (Stockholm, Sweden). The flour was then sifted to <132 μm (Simon Timer Series 20, Stockport, England) and stored in airtight containers at 4°C. The sample was defatted using the procedure of MacRitchie and Gras (1973). An air-classified high-protein fraction was obtained from Goodman Fielder (Dulwich Hill, NSW, Australia) and a fiber fraction was obtained from Food Science (North Ryde, NSW, Australia). The wheat flour used was a bakers' control flour (protein content 13.0%; moisture content 14.3%) (BRI Australia Ltd., North Ryde, NSW). Nitrogen content was determined by the Dumas total combustion method in an elemental analyzer (CHN-1000, Leco, St. Joseph, MI) and converted to protein content (N × 6.25). The albumin fraction for the foaming and emulsion analyses, either untreated or defatted (MacRitchie and Gras 1973), was derived from the procedure outlined in Blagrove and Gillespie (1975).

TABLE I
Cultivars and Species of Lupin Used

Species	Cultivar
Lupinus albus	Ultra
	Esta
	P20950-3
	75B09-2-3
	75B09-10-3
	Oram Bulk C
	Oram Bulk 4
	Multolupa
	Lucky-1
	Kiev Mutant
L. angustifolius	Gungurru
	Merrit
	Myallie
	Kalya

Dough Mixing

All dough formulations were mixed on a 2-g mixograph (TMCO, Lincoln, NE). Mixing trials were conducted using water absorptions calculated from the protein content and moisture of the blend (Approved Methods, AACC 2000). The quantities of flour and water thus calculated were scaled to provide a constant 3.5 g of dough. Preliminary experiments with 1.1, 1.2, 1.25, 1.3 and 1.4 mL of water showed that the optimum mixing time for a flour with 10% lupin substitution was achieved with exactly the same water content (62.5%) as the unsubstituted flour (1.25 mL). This amount was used for all levels of lupin substitution in the dough mixing, dough extension, and baking experiments.

In one experiment, defatted and untreated lupin flour of the 10 cultivars was substituted for wheat flour at 2, 5, 10, 15, and 20% levels, and an unsubstituted wheat sample was the control. In a separate experiment, a defatted or untreated high-protein fraction was substituted at the same levels and with the same control. Three replicates were prepared; attributes measured included mixing time (MT, time to reach peak resistance) and resistance breakdown (RBD, % drop in resistance 3 min after peak).

Dough Extension

Defatted and untreated lupin flour of all 10 cultivars was substituted for wheat flour at 5 and 10% levels, and an unsubstituted wheat flour was the control. Doughs for extension testing were mixed to peak development (MT) in a 2-g mixograph using 3.5 g of dough. Extension was tested in duplicate on a microextension tester with a 19-mm gap and 6-mm hook operating at 1 cm/sec. Dough samples for extension testing (1.7 g/test) were molded into cylinders ≈6 mm in diameter with a prototype molder, mounted on a sample carrier, and rested at 30°C and >90% rh for 45 min before extension testing (Gras and Békés 1996). The extension tester consisted of a moving carriage with a fixed hook attached to a force transducer. The forces were calibrated against known weights. Maximum resistance to extension (N) and extension before rupture (cm) were calculated using specialized software (Rath et al 1994).

Test Baking

Test baking was done in duplicate using 35 g of flour per loaf prepared in the mixograph (MacRitchie and Gras 1973). Samples

TABLE II
Analysis of Variance of Mixing Time, Resistance Breakdown, and Maximum Resistance to Extension of Wheat Doughs with Varying Amounts of Lupin Flours Added[a]

	Mixing Time		Resistance Breakdown		Maximum Resistance to Extension	
	df	Mean Square	df	Mean Square	df	Mean Square
Level (L)	4	8542.6***	4	83.53***	1	144609***
Defatting (D)	1	959.2*	1	48.49**	1	2860**
L × D	4	134.8 ns	4	29.86***	1	2379*
Accession (A)	9	12530.8***	9	562.32***	9	11135***
A × Species (S)	1	100258.5***	1	4991.43***	1	57616***
A × Cultivar (C)	8	1564.8***	8	8.68*	8	5325***
L × A	36	1264.3***	36	69.27***	9	935**
L × S	4	7638.2***	4	558.30***	1	265 ns
L × C	32	467.6***	32	8.15**	8	1019**
D × A	9	553.6**	9	19.24***	9	1863***
D × S	1	142.2 ns	1	32.44**	1	216 ns
D × C	8	605.0**	8	17.59***	8	2068***
L × D × A	36	396.7***	36	6.88*	9	356 ns
L × D × S	4	624.9*	4	15.01*	1	232 ns
L × D × C	32	368.2**	32	5.86 ns	8	372 ns
Residual	173	188.3	173	4.63	132	367

[a] *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; ns, not significant.

of defatted or untreated flour of *L. albus* cv. Ultra, the high-protein fraction, and the fiber fraction were substituted for wheat flour at 2, 5, 10, 15, and 20%; an unsubstituted wheat flour was the control. In a second experiment, nondefatted flours of 10 lupin cultivars were substituted for 5% of the wheat flour, with the same control. The formulation used flour (35 g), water (2 mL addition), and stock solution (19 mL). Stock solution (1L) consisted of bakers' grade salt (36 g), yeast (42 g), and improver at 100 ppm of ascorbic acid in malt flour (8.4 g). Each dough was mixed to optimum development, machine-molded using a specifically designed molder (CSIRO prototype) (Beasley et al 2002), sealed in an air-tight container, and rested for the initial fermentation of 20 min in a humidity cabinet (38°C). Each dough was remolded, placed in a lightly greased baking tin, and proofed for 45 min at 38°C and 95% rh in a humidity cabinet (Thermoline bread proving cabinet) before baking (Baker Perkins, Rotel Modular) for 15 min at 240°C.

The loaf was cooled before removal from the pan. Height measurements in duplicate were taken using a loaf height meter 20 min after removal from the oven (Gras and MacRitchie 1973). The following day, the loaf volume was determined in duplicate by weighing the loaf using a rapeseed displacement meter. It was then sliced open for visual examination. Duplicate color index readings of both the crust and crumb were made using a Minolta colorimeter (CR 300 series).

Foam Analysis

Foam analysis was done in collaboration with INRA, France. The protein concentration used was 1 mg/mL. All samples were prepared in 0.1*M* sodium phosphate buffer, pH 7.0, using Milli-Q water (surface tension 72.8 mN/m at 20°C). The solution was stirred overnight, then centrifuged for 10 min at 15,000 × *g*. The method and instrument details have been described in Baniel et al (1997) and Sarker et al (1998), and the column dimensions have been described in Sarker et al (1998). The height of the column of foam (35 mL) and the sparging of the test solution are all controlled by the governing software (Loisel et al 1993; Fains et al 1997) in response to the linear camera. The parameters include sparging time (sec), maximum volume of liquid in the foam (mL), volume of liquid in the foam at the end of bubbling (mL), and time for half drainage (sec), which was calculated as the time required to drain a liquid volume equal to half the total liquid drained during the experiment. Foam capacity (FC) was measured as the rate of foam formation determined by the slope (S_m) of the plot of the foam volume versus the time during bubbling (mL/sec) and the quantity of gas (mL) injected to reach a foam volume of 50 mL (FC).

Emulsion Analysis

Emulsion analysis was done in collaboration with INRA, France. To prepare the emulsions, 40 mg of sample was suspended in 20 mL of 0.1*M* phosphate buffer, pH 7.0, stirred overnight, then centrifuged for 10 min at 15,000 × *g*. The supernatant was collected for emulsion analysis. An automated conductimetric method was used to determine the kinetics of phase separation (Loisel and Popineau 1997). As the water phase and emulsified phase separated with the appearance of a creaming phase, the volume fraction of oil in the creamed phase increased from a value of 0.375 at time 0. A more stable emulsion was indicated by a slower change in the creamed volume fraction.

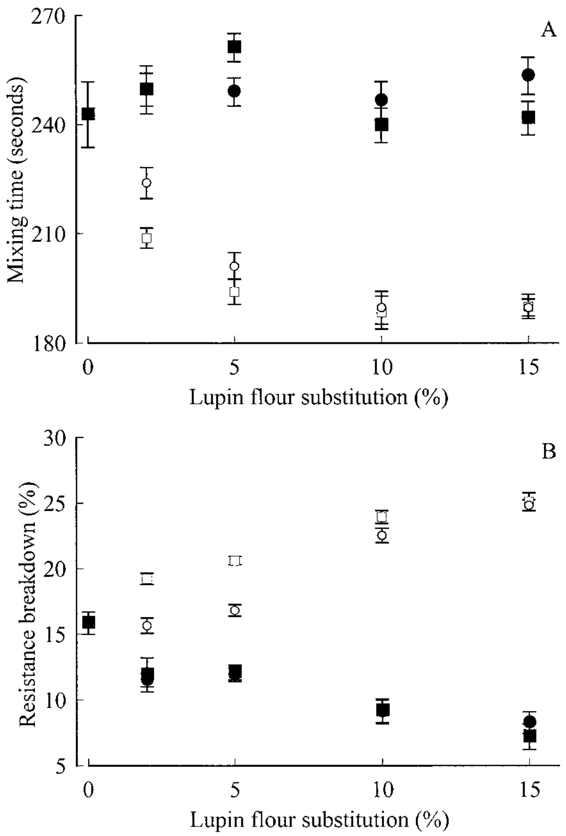

Fig. 1. Effect of lupin flour substitution on mixing time (**A**) and resistance breakdown (**B**). Nondefatted *Lupinus albus* (○); nondefatted *L. angustifolius* (●); defatted *L. albus* (□); defatted *L. angustifolius* (■). Error bars ± 1 standard error.

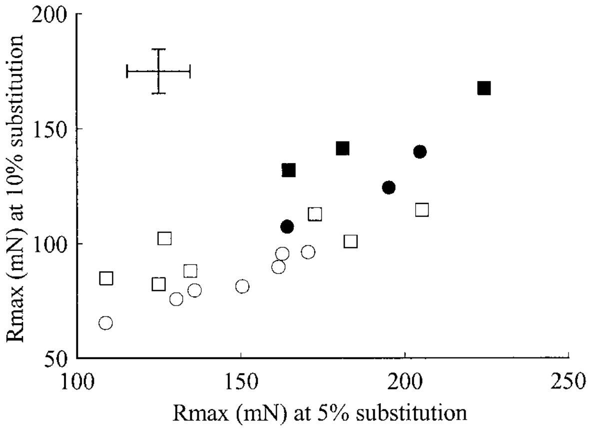

Fig. 2. Effect of two levels of substitution of several lupin flours on maximum resistance to extension of wheat-based dough. Nondefatted *Lupinus albus* (○); nondefatted *L. angustifolius* (●); defatted *L. albus* (□); defatted *L. angustifolius* (■). Error bars ± 1 standard error.

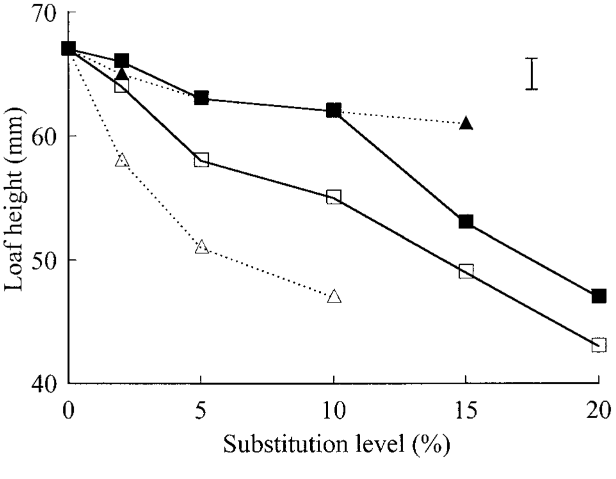

Fig. 3. Effects on loaf height of nondefatted lupin flour (■), defatted lupin flour (□), high-protein fraction from lupin flour (▲), and fiber fraction from lupin flour (△). Error bars ± 1 standard error.

Statistics

Statistical analyses for dough mixing, dough extension, and baking parameters were made using MSUSTAT v. 4.1 (Richard E. Lund, Montana State University, Bozeman, MT). For dough mixing, a multifactor analysis of variance was used on the cultivar data, while a two-way analysis of variance was used for high-protein data (Table II). For dough extension, a multifactor analysis of variance was used on the data once the wheat samples were removed because there were not enough replicates of the wheat flour control samples. To counteract this, a one-way analysis of variance was used to include the wheat samples. For the baking tests, a one-way analysis of variance was used on the data. Correlation coefficients were calculated on means across replicates. Foaming and emulsion parameters were subjected to analysis of variance using SuperAnova 1.11 (Abacus Concepts Inc., Berkeley, CA.)

RESULTS

Dough Mixing

Both mixing time and resistance breakdown showed that dough quality decreased progressively with increasing content of *L. albus* flour (Fig. 1), expressed as a mean for all six *L. albus* cultivars. On the other hand, *L. angustifolius* flours (means of four cultivars) had little effect on mixing time up to 15% substitution but caused a decrease in resistance breakdown (a positive attribute related to other baking properties). The decrease in mixing time for *L. albus* could be an advantage in commercial plant bakeries because it is important to increase the speed of production by reducing mixing time. Defatting provided no clear advantage in either. The effect of cultivar (within species) was significant (Table II), although the effect was not as great as the difference between species. However, *L. angustifolius* cv. Gungurru gave longer mixing time compared with other *L. angustifolius* cultivars.

Mixing time decreased with increasing content of high-protein lupin fraction (Table II) while resistance breakdown was not significantly affected (not shown).

Dough Extension

Extensibility for the wheat control flour was 13.1 cm. At the 5% substitution level of lupin in flour, it averaged 12.8 cm, which was not a significant difference (SE = 0.75). With 10% substitution, extensibility was significantly reduced to 11.5 cm. Cultivar and defatting did not significantly affect extensibility.

The maximum resistance to extension ($R_{\max}$) decreased with increasing content of lupin flour for both the untreated and defatted flour samples, although a smaller decrease was seen for the defatted samples (Fig. 2). The $R_{\max}$ in the wheat control was 253 N. The $R_{\max}$ was highest for *L. angustifolius* cvs. Gungurru and Merrit at both the 5 and 10% substitution levels, while *L. albus* cvs. Esta and Lucky-1 were the least extensible. Defatting the lupin flours before the mix increased the $R_{\max}$ in nearly all cultivars.

Baking

The level of substitution of lupin additive had a highly significant effect on loaf height (Fig. 3). Crumb structure was also adversely affected by higher levels of substitution. All forms of lupin additive reduced loaf height, with the greatest effect from the fiber fraction and the least from the high-protein fraction. Defatted lupin flour depressed loaf volume more than untreated lupin flour or the high-protein fraction. *L. albus* cvs. Multolupa and Lucky-1 had very little effect on loaf volume while *L. angustifolius* cv. Myallie had the greatest effect.

Beyond the 2% substitution level, both flour and high-protein fraction reduced crust color but crumb color showed little change. Crumb color depended much more on the cultivar used in the separate experiment. *L. albus* cv. Ultra caused the greatest reduction, 4.5 units from the control value of 60.3 (*L*), and *L. angustifolius* cv. Kalya, the greatest increase (4 units).

Foaming

The development of foam volume followed a very similar pattern regardless of whether flour or albumin was used and whether *L. albus* or *L. angustifolius* was the species used (Fig. 4A). Differences between cultivars were all highly significant for time of sparging (sec), maximum volume of liquid in foam (mL), volume of liquid in foam at end (mL), and the time for half drainage (sec). Time of sparging was ≈135 sec for all flour samples and was 2–12 sec longer for all albumin samples except that of Kiev Mutant, where it was 36 sec longer. For the BSA standard, the time of sparging

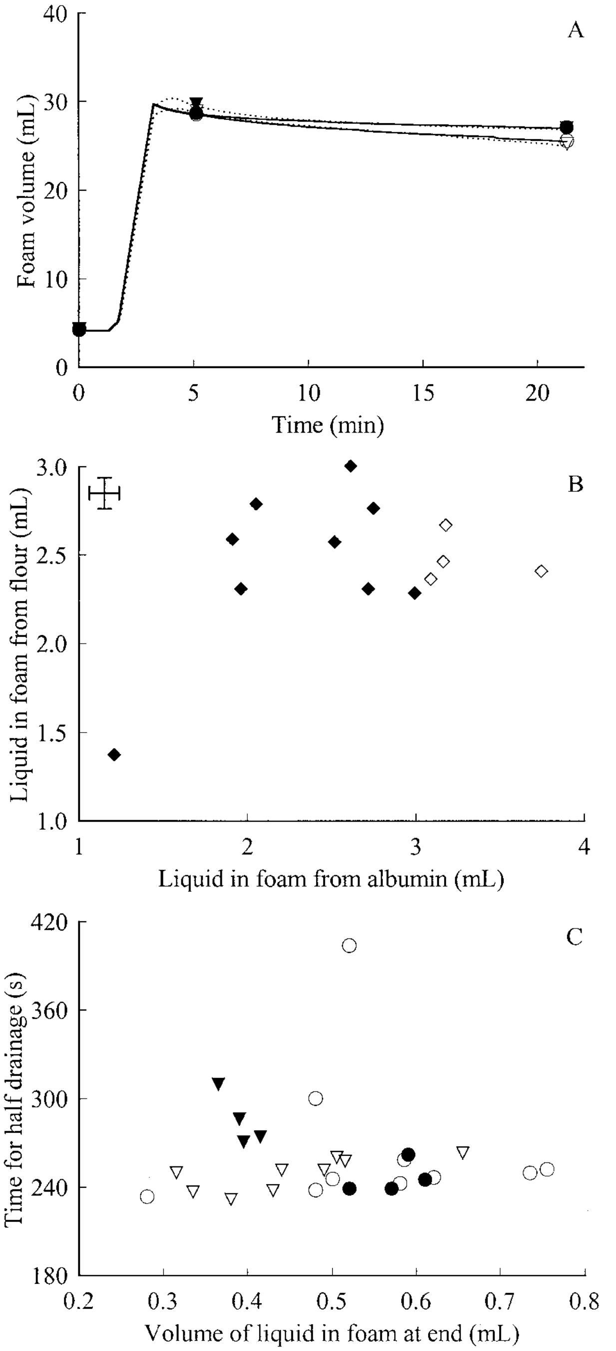

Fig. 4. A, Foam volume produced by lupin flour and albumin samples. *Lupinus albus* flour (○); *L. angustifolius* flour (●); *L. albus* albumin (∇); *L. angustifolius* albumin (▼). **B,** Maximum volume of liquid in foam from albumin samples plotted against that from flour samples. *L. albus* (◆); *L. angustifolius* (◇). **C,** Time for half-drainage (sec) plotted against volume (mL) of liquid in foam at the end of processing. *L. albus* flour (○); *L. angustifolius* flour (●); *L. albus* albumin (∇); *L. angustifolius* albumin (▼). Error bars ± 1 standard error.

was 195 sec. The maximum volume of liquid in the foam was greater from *L. angustifolius* albumin samples (Fig. 4B). There were only two *L. albus* cultivars that behaved in a similar way, those of cvs. Esta and Oram Bulk 4. Kiev Mutant provided the smallest volume overall. The flour samples from *L. angustifolius* gave lower volumes than the average for *L. albus*. The liquid volume from the BSA standard was 4.3 mL.

Flour samples generally gave a higher volume of liquid in foam at the end than the albumin samples (Fig. 4C). Kiev Mutant provided the lowest volume overall. The *L. albus* cultivars had a slightly higher volume for both flour and albumin at the end compared with *L. angustifolius* cultivars. Four of nine of the *L. albus* cultivars and all of the *L. angustifolius* cultivars had a higher time for half drainage for the albumin sample than for the flour sample, with the Ultra flour being a particular outlier.

L. angustifolius cv. Myallie and *L. albus* cv. Ultra provided the highest foam volumes, although all *L. angustifolius* cultivars appear to have higher foam volumes compared with *L. albus* cultivars (Fig. 4). For the albumin fraction, *L. angustifolius* cultivars overall produced higher foam volumes compared with *L. albus* cultivars, with *L. angustifolius* cvs. Gungurru and Merrit providing the highest foam volumes. For both the whole flour and the albumin fraction, the *L. albus* cv. Kiev Mutant provided the lowest foaming potential.

Emulsification

All lupin flour samples showed positive emulsification properties (Fig. 5), as shown by the increase in the volume fraction of oil remaining in the creamed phase with aging of the emulsion. There were no significant differences between species or cultivars in this attribute for lupin flour samples (Fig. 5A). However, for the albumin fraction (Fig. 5B), *L. angustifolius* cultivars lost emulsion volume much more rapidly (in 10–20 min) than the *L. albus* cultivars, most of which took ≈120 min for the oil fraction in the creamed phase to reach maximum. In this case, the defatted samples took a longer time to reach maximum (45 min) and had slightly lower oil volume fractions compared with the untreated samples.

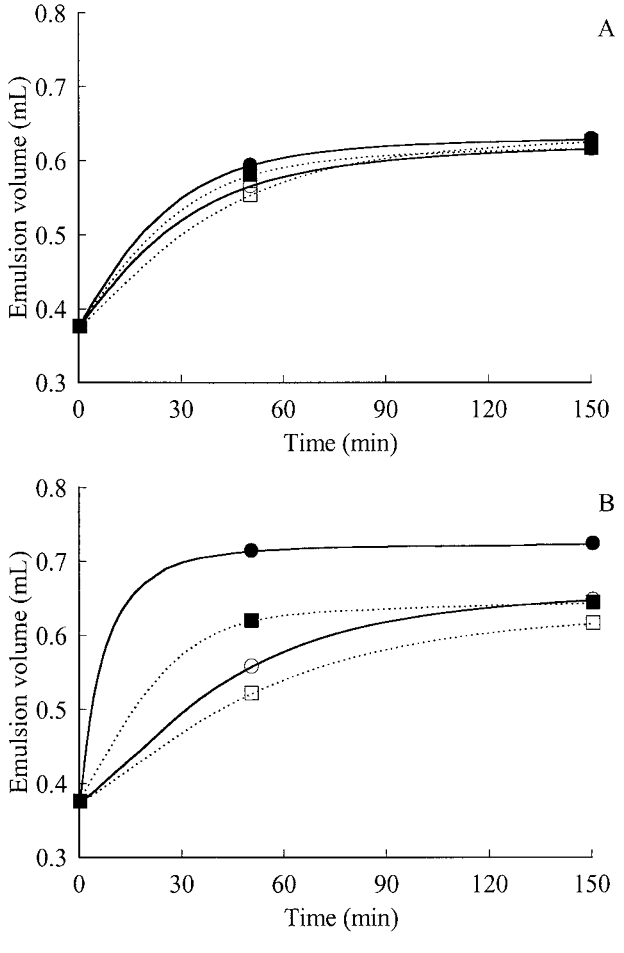

Fig. 5. Emulsion volume produced by lupin flour (**A**) and albumin (**B**) samples. Nondefatted *Lupinus albus* (○); nondefatted *L. angustifolius* (●); defatted *L. albus* (□); defatted *L. angustifolius* (■).

DISCUSSION

This article has dealt with the suitability of lupin flour for blending with wheat flour by dough mixing, extension, and breadmaking. There is a need to know which species and cultivars of lupin are best suited for use as food ingredients, and also to determine how much lupin flour can be incorporated into wheat flour to improve the nutritional value of the mixed lupin and wheat product without detrimental effects on the quality. For the Australian wheat industry, the three key dough-testing parameters are mixing time, resistance breakdown, and maximum resistance to extension (Cracknell, *personal communication*). These results have provided a sound basis for the incorporation of lupin proteins in food processing. The foaming and emulsion properties of lupin flours and fractions were also studied to determine the potential of these species for adding value to food. *L. albus* and *L. angustifolius* flours had strikingly different effects on many of the parameters measured.

Dough Mixing

Increasing substitution level of *L. albus* flour led to a decrease in mixing time and an increase in resistance breakdown, while *L. angustifolius* flour had the opposite effects. The high-protein fraction led to an increase in resistance breakdown. The nondefatted high-protein fraction had very little effect on peak resistance, but the defatted fraction reduced it greatly. Previous work on substituting lupin flour for wheat flour has been very limited. Lucisano and Pompei (1981) found that a longer mixing time was required to reach a maximum dough consistency when lupin flour (*L. albus* cv. Multolupa) was incorporated. Similarly, Misra et al (1991) found that for soy-wheat blends, the mixing time increased as the content of defatted soybean flour increased. In the present results, however, the substitution of *L. albus* flour decreased mixing time, and *L. angustifolius* flour had no consistent effect on it. In general, mixing time correlates well with dough strength and, hence, final loaf volume (Gupta et al 1993), but it also is a major contributor to the cost of production and many Australian wheats have an excessively long mixing requirement (Cracknell, *personal communication*; Wooding et al 1999). Therefore, a reduction in mixing time, without significantly affecting final loaf volume or quality, is a desirable outcome. *L. albus* cultivars showed useful variation in their effects on mixing time and loaf quality. The incorporation of flour from *L. albus* cultivars into strong-wheat flours could therefore be a useful application.

Defatting the flour before blending significantly lowered the mixing time for only half of the cultivars tested. The difference between untreated and defatted flour was attributable to lipid removal, as those cultivars that did not show a decrease in mixing time were not significantly different between the two flour types. Similarly, when soybean flours were added to bread mixes, mixing time was lower for the defatted than the untreated samples (Ranhotra et al 1974).

Resistance breakdown is, by definition, a measure of tolerance to overmixing where a lower resistance breakdown means greater mixing tolerance. On this basis, flour of *L. angustifolius* cultivars contributed tolerance to overmixing compared with the wheat control and *L. albus* cultivars. This could indicate that *L. albus* cultivars may be better used as an additive in other baked products that are less likely to be sensitive to overmixing, such as in biscuit (cookie) manufacture. The high-protein fraction had an effect similar to whole flour. Therefore, this effect may be due to the protein component of the flour.

Dough Extension

Substitution of flours from cultivars of *L. angustifolius* and *L. albus* gave similar values for $R_{\max}$. $R_{\max}$ was reduced by 20–55% at the 5% substitution level and even more at the 10% level. In eight of the cultivars, $R_{\max}$ was higher for the defatted treatment, with the lowest reduction coming from *L. angustifolius* cv. Merrit. $R_{\max}$ is a measure of dough strength (Gupta et al 1993) and was correlated with mixing time, peak resistance, resistance breakdown, and extension.

Baking

The substitution of whole lupin flour for wheat flour decreased loaf height and increased the darkness of the crust and crumb color. For a high-protein lupin fraction, the loaf height and crust color were maintained, while the darkness of the crumb color increased. *L. albus* cultivars produced larger loaves with darker coloration than *L. angustifolius.* In general, grain legume flour additives have been associated with reduced loaf volume (Fleming and Sosulski 1977). Substitution of defatted soy flour at >2% was associated with reduced loaf volume (Misra et al 1991), unless native or synthetic glycolipids were also added, in which case, soy flour could be substituted at 16% (Hyder et al 1974). Similarly, Tsen and Hoover (1973) reported that baking quality of defatted soy flours was inferior to that of the full fat (untreated) flours because the naturally occurring emulsifiers, lecithin and glycolipids, were removed during the extraction process.

In the present work, increasing lupin substitution resulted in decreasing loaf volume, as also found by Lucisano and Pompei (1981) and similarly for soybean flours (Finney et al 1963), field pea concentrate (Anonymous 1974), faba bean concentrate (McConnell et al 1974), and sunflower (Rooney et al 1972). Nevertheless, loaf quality can still be viewed as acceptable at slightly reduced loaf volumes. El-Dash and Sgarbieri (1980) viewed loaves made with 10% lupin substitution as having “satisfactory” quality. Lucisano and Pompei (1981) stated that the reason for the gradual decrease in loaf volume was due to the loaf cell structure being unable to retain gas during proofing and baking. Sosulski (1983) commented that the gluten matrix was subjected to a greater stress in sections that covered the starch granules, permitting gas to escape, resulting in a low loaf volume. This effect was seen in the present results, where loaves with high lupin content had poor crumb structure. Similarly, compact crumb structure was seen for full-fat soybean flours (Rastogi and Singh 1989).

Whereas mixing and extension tests are used reliably to predict aspects of baking studies, the results suggest that this assumption may not be so reliable when composite flours are involved. In fact, the lack of significant correlation between loaf height and mixing parameters was particularly encouraging because it indicated that it should be possible to identify or develop materials that reduced mixing time without adverse effects on loaf volume, particularly within *L. albus*.

The present study with fiber and high-protein fractions illustrated the different contributions of the various components of the flour to effects on loaf volume. Fiber had the greatest adverse effect and, as noted previously, the major effect of lupin flour on decreasing mixing time and increasing peak resistance was ascribed to the fiber fraction. Pomeranz et al (1977) found that fiber lowered loaf volume while increasing mixing time, and attributed this to a lower gas retention rather than unsatisfactory gas production. Nondefatted flour had a less adverse effect than defatted, suggesting that the lipid may counteract some of the negative effects of the fiber. The low effect of the (nondefatted) high-protein fraction on loaf volume was in agreement with its low effect on mixing time. There was not enough defatted high-protein material for a baking test, but its effects on peak resistance were so adverse that it may be surmised that it could also reduce loaf volume. This suggests that high-protein lupin fractions have great potential to be used as bakery additives and for other novel end uses. Similarly, Fleming and Sosulski (1977) reviewed various plant proteins and concentrates of soybean, field pea, and faba bean, showing loaf volume deterioration when levels >5–8% were incorporated. Therefore, lupin has the potential to be at least competitive with other grain legumes for substitution at higher levels (≤15%).

Loaf crumb structure was acceptable at a 5% substitution level, but not at a 10% substitution level with *L. albus* cv. Ultra. This cultivar was much poorer in loaf height at 5% substitution than *L. albus* cvs. Multolupa and Lucky-1. These two cultivars, and perhaps others as yet untested, may give acceptable crumb structure at 10% substitution. This would be a significant advantage where nutrition is limited by amino acid composition. Lupin fiber, however, does not appear to be a suitable bread additive as a means of increasing dietary fiber. The color index for the *L. albus* cultivars was lower than the *L. angustifolius* cultivars, which further favors *L. albus* for use in varying breads from the typical “white” all-wheat loaf.

Foaming

L. angustifolius cultivars produced higher foaming volumes than did the *L. albus* cultivars, and *L. angustifolius* cv. Myallie had the highest foaming potential. However, none of the lupin materials provided as good a foam as the BSA control. *L. angustifolius* albumins held more liquid in the foam than *L. albus* and also held it for a longer time, suggesting that this species probably has more potential as a source of suitable foaming materials. The poor performance of *L. albus* cv. Kiev Mutant was particularly marked. Comparison of the lupin results with those for BSA may be an unfair basis for assessing the foaming potential of lupins because Mitchell (1986), reviewing the foaming properties for proteins, showed that BSA has a better foam volume than egg albumin, although with half the stability level. These values cannot be directly compared with the values obtained during the present work, but the trend can be, indicating that lupin flour has a potential to be used as a suitable substitute for egg albumin as a foaming agent in foods.

The foaming studies performed on lupin in the past have used a Waring blender to whip the foam (Sathe et al 1982). Other techniques employed to produce a foam include injection, sparging, and shaking (Waniska and Kinsella 1979), each having its advantages, although whipping is the most frequently used. Whipping must be performed manually, leading to difficulties of reproducibility. Different types of mixers with varying conditions have been used to produce foams, so it is difficult to derive meaningful comparisons. To overcome this problem, Kato et al (1983) first derived a bubbling method for producing comparable foams that was later automated by Baniel et al (1997). This method was based on conductimetric and optical measurements, making it possible to determine the foaming properties of proteins reproducibly (Loisel et al 1993). This was the procedure used in the present study.

Sathe et al (1982) reported on the effects of concentration, salt, pH, and carbohydrates on the foaming capacity of lupin proteins and found that foam stability was strong after 36 hr for both the flour and protein concentrate. Defatting increased the foaming capacity of the protein concentrate by 8%, although these foams were less stable than the undefatted protein concentrate and flour. The difference due to defatting was more extreme in the present results, where nondefatted flours or albumins did not reach the required 35 mL volume to constitute a valid test. Sosulski and Youngs (1979) reported that lipids in lupin and chickpea reduced foaming properties of flours and air-classified products, although values for defatted soybean were high. The reason for low foaming potential of nondefatted flour was that different lipids have different effects on foam structure. In general, the more polar lipids (glycolipids, phospholipids) act as foam stabilizers (MacRitchie 1977). They act by absorbing at the air-aqueous interface and forming stable films. The more nonpolar lipids (triglycerides) are weakly surface active and tend to give condensed monolayers (low compressibility) which can be desorbed more easily.

Raymundo et al (1998a) found that the higher foaming capacities were obtained after thermal denaturation was applied to the high-protein sample (*L. albus*) and the foam stabilizer that had the largest foam capacity increase was xanthan gum (Raymundo et al 1998a).

Emulsifying

Albumins extracted from *L. angustifolius* cultivars gave greater emulsion breakdown than the corresponding crude flours or either fraction (untreated or defatted) from *L. albus*, and did so more rapidly. *L. angustifolius* cv. Gungurru had the highest emulsion breakdown, regardless of treatment. The emulsion volumes obtained for the albumin component from *L. angustifolius* proteins provided more rapid breakdown compared with the flour samples. In contrast, lupin-protein concentrates had better emulsifying capacity and poorer emulsion stability than the whole flour (Sathe et al 1982). More recently, Raymundo et al (1998b) increased emulsion stability by thermal treatments, which favored protein unfolding, yielding the development of an entanglement network. King et al (1985) showed that lupin-protein isolates had an emulsifying capacity similar to that of soybean isolates. Emulsifying properties are thus a promising functional characteristic for the further development of lupins.

CONCLUSIONS

Of the two species, *L. albus* has shown greater potential as a bread additive because loaf height and structure were maintained, while mixing time was usefully reduced and nutritional quality was improved. The substitution level that provided the best bread quality for the whole lupin flour was maintained up to 5%; thereafter decreasing in quality attributes. The detrimental effects at higher substitution levels appeared to be associated with the nonprotein components of the lupin flour. *L. angustifolius* has greater potential for foaming, although defatting was necessary, and the extracted albumin component performed only slightly better than the whole flour. Further investigation will be necessary to establish whether specific subfractions are responsible for these properties. If such fractions are identified, there may be justification for the development of systems for subfractionation on an industrial scale. In addition, breeding technology should be directed toward the identification and production of germplasm with improved content of these components.

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