CSIRO PUBLISHING

Crop & Pasture Science, 2018, **69**, 892–903
https://doi.org/10.1071/CP18205

Relationship between seed traits and pasting and cooking behaviour in a pulse germplasm collection

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Abstract. Development of food products from legume flours is increasing. Seed and flour characteristics must be analysed for selection of the best screening quality traits. With this purpose, germplasm collections of faba bean (*Vicia faba*), chickpea (*Cicer arietinum*), lentil (*Lens culinaris*) and grass pea (*Lathyrus sativus*) were evaluated for their physicochemical, pasting and cooking characteristics. The accessions were grouped accordingly to several seed traits (size, shape, colour, variety and surface) that affected final viscosity, cooking time, hydration capacity and seed weight. In general, seed weight was correlated with hydration capacity. Among species, faba bean revealed higher values of pasting parameters. Cooking time was significantly negatively correlated with final viscosity (–0.298) and positively correlated with seed weight (0.601). The general variance was analysed by using principal component analysis, which allowed identification of specific accessions with important traits such as higher protein or fibre content, hydration capacity or seed weight.

Additional keywords: phenology, pulses.

Received 9 May 2018, accepted 13 July 2018, published online 31 August 2018

Introduction

Pulses are grain-legume crops harvested for dry grain and include beans, lentils (*Lens culinaris*), chickpeas (*Cicer arietinum*) and peas (FAO 1994). Their food use is increasingly supported by the promotion of healthy lifestyle and diets in order to prevent cancer, cardiovascular diseases, diabetes and obesity (Santos *et al*. 2017). The year 2016 was declared by the United Nations as the International Year of Pulses, with the aims of implementing a plan of action to increase awareness of the importance of legumes to human health, and increasing production and consumption of pulses (FAO 2015).

Latest FAO reports show that the production of pulses is increasing, with the latest data showing an annual production of 77 Mt worldwide (FAO 2014). Of this, dry beans represent ~33%, chickpeas 17%, dry peas 15% and lentils 7% (FAO 2016). Despite the trend of increasing worldwide production and considering pulses as protein crops, there is a gap between demand and supply, mainly in Europe (Häusling 2011).

With their gluten-free profile, high protein and fibre content, and low glycemic index, these grain legumes have lately been regarded as valuable alternative ingredients for the production of flours to be used in the development of new food formulations (Vaz Patto *et al*. 2015; Carbas *et al*. 2018). Examples include noodles (Song and Yoo 2017), pastas (Howard *et al*. 2011), biscuits (Sparvoli *et al*. 2016; Dauda *et al*. 2018) and cakes (Belghith-Fendri *et al*. 2016; Shaabani *et al*. 2018). As such, for quality improvement in breeding programs and for the selection of the best genetic material, certain traits must be characterised for genetic diversity within different germplasm collections. In chickpea collections, physical parameters such as size, shape and colour have been shown to affect variation in quality parameters including protein, fibre and fat content (Serrano *et al*. 2017). In addition, seed traits such as seed weight, hydration capacity and cooking time vary with chickpea genotype (Tripathi *et al*. 2012). However, significant effects of growing environment and storage conditions on physical and

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biochemical characteristics of grain legumes have also been reported (Sharma *et al*. 2014; Goyal *et al*. 2015).

Another advantage of legume seeds over cereal grains is their lower digestibility, associated with higher content of resistant starch (and lower glycemic index, referred to above) (Hoover and Zhou 2003). Starch pasting properties characterise the dissolution of starch and depend on physical and chemical characteristics of starch granules, being directly related to the development of viscosity (Atwell *et al*. 1988), and varying with the source of pulse starch and genotype under analysis (Byars and Singh 2016). These parameters affect the cooking and eating quality of the final products, so are key in the evaluation of legume flours as potential new ingredients in nutritionally improved formulations (Giuberti *et al*. 2015; Carbas *et al*. 2018).

The composition and structure of several pulse starches from specific varieties have been studied (Byars and Singh 2016; Carbas *et al*. 2018); however, little information is available on the diversity of rheological properties among accessions of large set of germplasm, which is necessary for the identification of outstanding accessions and their incorporation into breeding programs.

The goals of this study were to characterise the diversity of pasting and cooking properties among germplasm collections of faba bean (*Vicia faba*), chickpea, lentil and grass pea (*Lathyrus sativus*), and to identify outstanding accessions and understand the variation obtained by specific seed traits (e.g. colour, size, shape, surface and variety). Understanding the relationships between these factors, and how they influence each other, will contribute to the development of legume-based food products with desirable health benefits and sensory qualities.

Materials and methods

Plant material

For the study, 319 accessions were evaluated: 88 faba bean (accessions LEGVF 801–888), 86 chickpea (LEGCA 601–731), 47 lentil (LEGLC 401–509) and 98 grass pea (LEGLS 1–113). Faba bean accessions were selected from the germplasm breeding collection at IAS-CSIC (Córdoba, Spain), the CRF germplasm bank (Madrid), and the germplasm collection at INIAV-Oeiras, Portugal (WIEWS code PRT005). Chickpea accessions were selected from the germplasm breeding collection at IFAPA (Córdoba) and from the ICARDA germplasm bank. Lentil accessions were selected from the CRF germplasm bank. Grass pea accessions were selected from USDA (USA) and CRF germplasm banks and from the IAS-CSIC breeding collection. The accessions were multiplied in Córdoba during 2014, under the same field conditions, and irrigated and hand-weeded as needed. Harvest was performed by hand and seeds were stored at 5°C before analysis.

Seed-trait classification

Classification of seed traits was based on information collected from different genetic resource databases, and classes were adapted according to the variability found for faba bean (Genesys Plant Genetic Resources 2017), chickpea (Integrated Breeding Platform 2014), lentil (Cristóbal *et al*. 2014) and grass pea (Rybiñski *et al*. 2008).

Faba bean seeds were classified according to seed dimensions (very small <10 mm by <13 mm, small 10–13 mm by 13–19 mm, medium 13–16 mm by 19–25 mm, large 16–20 mm by 25–30 mm, very large >30 mm by >20 mm) and colour (brown, dark brown, dark green, light brown, light green, mixed). Chickpea seeds were classified according to variety type (desi, kabuli), shape (angular, pea shaped, owl's-head shaped), surface (smooth, rough, intermediate), seed size (very small <6 mm, small 6–8 mm, medium 7–9 mm, large 9–10 mm, very large >9 mm), and colour (black, brown, light brown, reddish brown, beige, light yellow, yellow brown, green, black brown, mosaic). Lentil seeds were classified according to size (small ≤3 mm, large >3 mm) and colour (brown, green, dark brown, mixed). Grass pea seeds were classified according to size (small <7 mm, medium 7–9 mm, large >9 mm), shape (triangular, rhomboid, round) and colour (cream, cream beige, cream red, cream white, cream green, brown, red brown, green brown, dark brown, brown grey, grey, mixed).

Physico-chemical and cooking characteristics

All four germplasm collections were evaluated for the following characteristics:

(i) 100-Seed weight (g): 100 seeds from each harvested accession were randomly selected and weighted.
(ii) Hydration capacity (%): assessed by weighing 100 whole seeds and soaking for 16 h at room temperature. At the end of the soaking period, seeds were drained and reweighed to calculate weight difference, inferring the hydration capacity.
(iii) Unhydrated seeds: the seeds that remained entirely or partially unswollen after the 16-h soaking period.
(iv) Cooking time (min): estimated by the Mattson Cooker method (Ribeiro *et al.* 2007), using an adapted Mattson device with 32 pins of 98 g. Samples of 40 seeds were soaked in distilled water (volume twice the sample) for 16 h at room temperature before cooking. The soaked samples were then positioned in each of the 32 cylindrical holes in the Mattson device, so that the pins were in contact with the surface of the seeds. The Mattson device was placed into an electric rice cooker containing 2 L boiling water. Seeds were considered cooked when the tip of the brass rod passed through the seed. Cooking time was recorded in the passage of the 13th pin and stopped at maximum of 120 min.

Pasting properties and basic composition

Pasting properties were determined by using a rapid visco analyser according to an adaptation of the AACC 76-21 method (AACC 1999). Pasting analyses were conducted on duplicate flour samples (3 g in 25 mL water), held at 50°C for 1 min, heated at 12°C min^{-1} to 95°C, held at 95°C for 2.5 min, cooled subsequently at 12°C min^{-1} to 50°C, and held at 50°C for 3 min. The peak, trough, breakdown, final viscosity and setback from trough were expressed in centipoise (cP).

Contents of protein, fibre and fat were assessed with a near-infrared (NIR) analyser (MPA; Bruker, Billerica, MA, USA) with ground-flour calibrations for grain legumes provided by

Bruker (n >500; $R^2 > 90$). NIR data were validated with 10% of the samples selected to cover the range and characterised by the following reference methods: protein by the combustion method ISO 16634-2:2016 (ISO 2016), calculated by multiplying nitrogen concentration by a conversion factor of 6.25; fat extracted by using petroleum ether in a Soxhlet apparatus according to ISO 6492 : 1999 (ISO 1999); and fibre by the intermediate filtration method ISO 6865 : 2000 (ISO 2000).

Statistical analyses

Data were analysed by using GraphPad Prism version 7.00 for Mac OS X (GraphPad Software, La Jolla, CA, USA; https://www.graphpad.com/). The variation within each seed trait was analysed by one-way analysis of variance, and Pearson correlation coefficients between traits were determined. Statistical significance was considered if $P < 0.05$.

Overall variation of physico-chemical, cooking, rheological and basic compositional characteristics within each species was assessed by principal component analysis (PCA), using Tanagra data mining software, version 1.4.5 (Lumière University Lyon 2, Lyon, France) (Rakotomalala 2005).

Results and discussion

Physico-chemical and pasting characteristics of the germplasm collections of faba bean, chickpea, lentil and grass pea

Average values of 100-seed weight, hydration capacity, unhydrated seeds and cooking time were calculated (Table 1). In general, faba bean seeds had the highest value of 100-seed weight (range 21–196 g) and lentils and grass peas the lowest (respective ranges 1.5–6 g and 6–37 g). Indeed, seed weight has been shown to be a morphological parameter that varies greatly among faba bean germplasms (Yahia *et al.* 2012; Backouchi *et al.* 2015). The mean hydration capacity for all four species varied in the range 100–120%, and the percentage of unhydrated seeds was highest in faba bean germplasm, reaching ~21%. Chickpea showed the highest values for cooking time, ranging from 16 to 120 min, and showing a large variability among genotypes, as previously reported (Tripathi *et al.* 2012). The small seed size of lentil prevented determination of its cooking time with the Mattson cooker.

Pasting properties give important information about flour quality and consistency (Offia-Olua 2014), these being important predictors for new product sensorial analysis. Here, pasting properties varied between species; faba bean accessions had higher mean values for peak and trough viscosity (>2500 cP), breakdown (>250 cP), final viscosity (>4000 cP) and setback (>1500 cP) (Table 1). Lentil and grass pea accessions, as seen for 100-seed weight, showed the opposite behaviour to faba bean, with lower mean peak and trough viscosity (<700 cP) and final viscosity (<1100 cP). Because peak viscosity values are indicative of the strength of pastes and the extent of granule swelling (Liang and King 2003), these results suggest that lentil, grass pea and chickpea flours seem suitable to endure high-temperature processes in formulation of food products.

Correlation analysis among physico-chemical and pasting properties

Correlation coefficients among physico-chemical and pasting properties were calculated for each species independently, in order to understand the relationships between properties within germplasm collections (Tables 2–5). In general, all pasting parameters were correlated, which was expected.

For the collection of faba bean germplasm (Table 2), negative Pearson correlations ($P < 0.01$) between final viscosity and seed weight, hydration capacity and cooking time were found. Higher seed weight correlated positively with higher protein content, hydration capacity and cooking time. Despite the tight

Table 1. Average ± residual standard deviation of seed parameters for the germplasm collections of faba beans, chickpeas, lentils and grass peas
n.d., Not determined

Parameter	Faba bean	Chickpea	Lentil	Grass pea
100-seed weight (g)	92 ± 37	28 ± 40	3 ± 38	15 ± 56
Hydration capacity (%)	104 ± 12	118 ± 14	110 ± 9	119 ± 14
Unhydrated seeds (%)	21 ± 38	0 ± 365	n.d.	7 ± 84
Cooking time (min)	68 ± 51	91 ± 39	n.d.	38 ± 89
Peak (cP)	2952 ± 12	884 ± 22	581 ± 14	616 ± 17
Trough (cP)	2700 ± 15	836 ± 19	530 ± 14	595 ± 17
Breakdown (cP)	252 ± 45	48 ± 93	51 ± 49	21 ± 74
Final viscosity (cP)	4268 ± 15	1135 ± 25	844 ± 18	1015 ± 16
Setback (cP)	1568 ± 21	300 ± 53	314 ± 29	419 ± 23
Protein (%)	24 ± 8	19 ± 11	26 ± 7	28 ± 37
Fibre (%)	9 ± 8	6 ± 36	6 ± 12	6 ± 12
Fat (%)	1 ± 18	6 ± 14	2 ± 10	1 ± 37

Table 2. Correlation coefficients of different traits in the faba bean germplasm collection
FV, Final viscosity; SB, setback; SW, 100-seed weight; HC, hydration capacity; US, unhydrated seeds; CT, cooking time. *$P < 0.05$; **$P < 0.01$

	Trough	Breakdown	FV	SB	SW	HC	US	CT	Protein	Fibre	Fat
Peak	0.96**	–0.151	0.874**	0.582**	–0.144	0.025	–0.086	–0.078	–0.093	–0.176	–0.029
Trough		–0.427**	0.916**	0.614**	–0.180	0.007	–0.066	–0.131	–0.069	–0.134	–0.079
Breakdown			–0.402**	–0.283**	0.166	0.056	–0.043	0.204*	–0.057	–0.094	0.182
FV				0.880**	–0.384**	–0.224*	–0.016	–0.298**	–0.368	–0.119*	0.070
SB					–0.541**	–0.449**	0.048	–0.430**	–0.641**	–0.075*	0.230*
SW						0.746**	0.109	0.601**	0.418**	–0.099	–0.185
HC							–0.276**	0.360**	0.331**	0.027	–0.168
US								0.195	0.059	–0.209	–0.127
CT									0.400**	–0.134	–0.268*
Protein										–0.150	–0.646**
Fibre											0.472**

Table 3. Correlation coefficients of different traits in the chickpea germplasm collection
FV, Final viscosity; SB, setback; SW, 100-seed weight; HC, hydration capacity; US, unhydrated seeds; CT, cooking time. $^{*}P < 0.05$; $^{**}P < 0.01$

	Trough	Breakdown	FV	SB	SW	HC	US	CT	Protein	Fibre	Fat
Peak	0.98**	0.757**	0.953**	0.754**	0.443**	–0.049	–0.096	0.044	–0.602**	–0.620**	0.572**
Trough		0.623**	0.913**	0.664**	0.473**	–0.047	–0.087	0.036	–0.617**	–0.663**	0.605**
Breakdown			0.804**	0.844**	0.211	–0.044	0.101	0.058	–0.367**	–0.279**	0.283**
FV				0.911**	0.439**	–0.056	–0.123	0.097	–0.570**	–0.540	0.551**
SB					0.329**	–0.056	–0.137	0.141	–0.421**	–0.320**	0.399**
SW						–0.218*	–0.292**	0.069	–0.304**	–0.702**	0.649**
HC							–0.052	0.181	0.064	0.073	0.048
US								–0.237*	0.145	0.166	–0.235*
CT									–0.239*	0.102	0.161
Protein										0.403**	–0.591**
Fibre											–0.751**

Table 4. Correlation coefficients of different traits in the lentil germplasm collection
FV, Final viscosity; SB, setback; SW, 100-seed weight; HC, hydration capacity. $^{*}P < 0.05$; $^{**}P < 0.01$

	Trough	Breakdown	FV	SB	SW	HC	Protein	Fibre	Fat
Peak	0.96**	0.509**	0.886**	0.720**	0.323*	–0.303*	0.167	–0.238	0.033
Trough		0.235	0.915**	0.733**	0.270	–0.344*	0.128	–0.262	0.041
Breakdown			0.252	0.235	0.275	–0.001	0.182	–0.022	–0.012
FV				0.945**	0.264	–0.374**	0.124	–0.205	–0.103
SB					0.227	–0.354*	0.105	–0.133	–0.206
SW						0.342*	0.301*	–0.091	0.011
HC							0.246	0.040	–0.078
Protein								0.419**	0.123
Fibre									0.312*

Table 5. Correlation coefficients of different traits in the grass pea germplasm collection
FV, Final viscosity; SB, setback; SW, 100-seed weight; HC, hydration capacity; US, unhydrated seeds; CT, cooking time. $^{*}P < 0.05$; $^{**}P < 0.01$

	Trough	Breakdown	FV	SB	SW	HC	US	CT	Protein	Fibre	Fat
Peak	0.99**	0.206*	0.838**	0.382**	0.618**	–0.067	–0.076	–0.021	–0.080	–0.161	0.317**
Trough		0.062	0.845**	0.384**	0.594**	–0.072	–0.077	–0.015	–0.098	–0.162	0.331**
Breakdown			0.063	0.041	0.319**	0.024	0.002	–0.066	0.212*	–0.038	–0.111
FV				0.818**	0.449**	–0.235**	–0.017	–0.021	–0.174	–0.199	0.403**
SB					0.152	–0.334**	0.051	–0.020	–0.200	–0.177	0.351**
SW						0.348**	–0.211	–0.108	–0.020	–0.226*	0.103
HC							–0.368**	–0.029	0.160	0.124	–0.169
US								0.013	0.144	–0.151	–0.049
CT									–0.057	0.079	–0.044
Protein										0.337**	–0.387**
Fibre											0.029

association among seed size and cooking times, accessions LEGVF816, LEGVF822 and LEGVF823 exhibited high 100-seed weight (>120 g) and low cooking times (<50 min); therefore, those genotypes can be useful for breeding programs.

In the chickpea germplasm collection, significant negative correlations were found between protein, fibre and pasting properties, as well as a positive correlation of fibre and pasting properties with seed weight (Table 3).

As seen for faba bean seeds, a negative correlation was found ($P < 0.01$) between final viscosity values and hydration capacity in lentil seeds (Table 4) and grass pea seeds (Table 5). In grass pea seeds, no significant correlation was identified with cooking time.

In other studies, different physico-chemical properties such as composition, crystallinity and gelatinisation behaviour were shown to be linked to pasting properties of, for example, beans, lentils, chickpeas and pea seeds (Chung *et al*. 2008; Joshi *et al*. 2013; Carbas *et al*. 2018). In the present study, new traits were correlated with pasting properties, which assists in understanding the final rheological behaviour in flours of different legume species.

Seed-trait variability within germplasm collections

The means of peak, trough, break, final viscosity, setback, seed weight, hydration capacity, unhydrated seeds and cooking time for each seed trait according to germplasm collection are provided in appendices (Appendix 1–4). Given the correlation analysis presented above, final viscosity, seed weight, hydration capacity and cooking time were selected as the parameters that most vary, and are shown as the dependent variable in relation to each seed trait (Figs 1–4).

In faba bean accessions, seeds were mainly distributed in small ($n = 31$), medium ($n = 29$) and large ($n = 15$) seed-size classes. As size increased, final viscosity values significantly decreased, whereas seed weight, cooking time and hydration capacity significantly increased (Fig. 1*a*). Considering the colour trait (Fig. 1*b*), there was a large amount of genetic variance, 32 of the 86 accessions categorised light brown, 14 light green, 13 mixed, 11 brown, 10 dark green, and six dark brown in colour. Seeds with light green colour seemed to show different behaviour with regard to seed weight and cooking time ($P < 0.05$) (Fig. 1*b*).

Chickpea germplasm was mainly divided into the two well-described varieties, desi ($n = 26$) and kabuli ($n = 50$). Kabuli seeds showed significantly higher seed weight (33 g *v.* 19 g for desi seeds), which is similar to previous findings, where kabuli seeds weighed 17.6 g and desi seeds 35.7 g (Tripathi *et al.* 2012). Kabuli seeds are usually described as having thinner seed coat (Serrano *et al.* 2017), and here, they had significantly higher final viscosity values (Fig. 2*a*). Besides being influenced by variety, final viscosity also significantly varied with seed shape (Fig. 2*b*), being higher in seeds of owl's-head shape, whereas cooking time was much lower in these accessions. Bigger seeds had higher seed weight, as expected (Fig. 2*c*), and surface type did not affect the parameters under study (Fig. 2*d*). Most chickpea accessions were divided among beige ($n = 27$) and light yellow ($n = 25$) colour categories, and these two groups differed significantly for seed weight (Fig. 2*e*).

The lentil germplasm collection was divided between small ($n = 20$) and large ($n = 27$) seeds, which differed only in seed weight (Fig. 3*a*). With separation by seed colour, green lentil seeds had lower seed weight (Fig. 3*b*).

Among grass pea accessions, rhomboid seeds ($n = 30$) had higher final viscosity and seed weight values ($P < 0.05$), whereas round seeds ($n = 9$) had higher cooking times ($P < 0.05$) (Fig. 4*a*). Most grass pea seeds were of medium size ($n = 43$), and these significantly differed from large seeds ($n = 23$) in final viscosity and seed weight (Fig. 4*b*). As seen in chickpea seeds, grass pea accessions varied greatly in colour, the most prevalent colour being cream beige, which, alongside mixed colour ($n = 10$), had the lowest cooking time (Fig. 4*c*).

Overall variation of physico-chemical and pasting properties within species

We included the compositional data relative to protein, fibre and fat contents in the PCA because there were several significant correlations. These three variables were added to peak, setback, 100-seed weight, cooking time, hydration capacity and unhydrated seeds, giving nine variables in total under analysis (Fig. 5).

Our results demonstrate the inherent heterogeneity of faba bean germplasm, with wide phenotypic variation (Fig. 5*a*), as shown by others (Karaköy *et al.* 2014). The first and second principal components explained 36% and 18% of total variance, respectively, accounting for 54% of variance. On the factor-loading plot, we found that protein content was correlated with cooking time, hydration and 100-seed weight, and the positions of the accessions LEGVF841, LEGVF887, LEGVF873, LEGVF888, LEGVF886 and LEGVF884 allow inference about their high protein content and associated factors.

For chickpea accessions, variability by basic composition has been demonstrated (Serrano *et al.* 2017). Here, the resulting components of the PCA for chickpea explained 52% of total variance: 37% for the first component and 15% for the second (Fig. 5*b*). In general, fat content seemed more related to the viscosity parameters (peak and setback). Accession LEGCA604 presented the greatest hydration capacity, whereas accessions

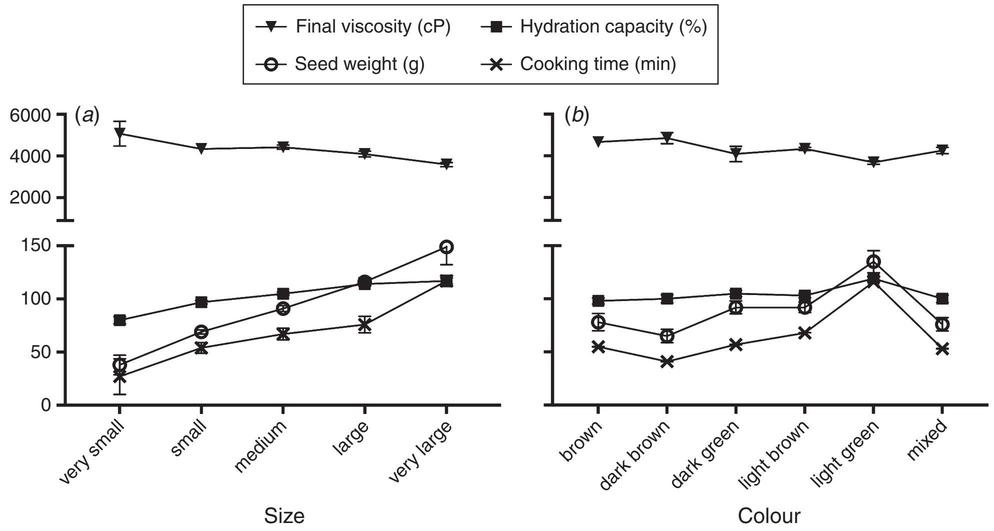

Fig. 1. Mean ± s.e. values of final viscosity, hydration capacity, seed weight and cooking time for faba bean germplasm collection for each class of seed (*a*) size and (*b*) colour.

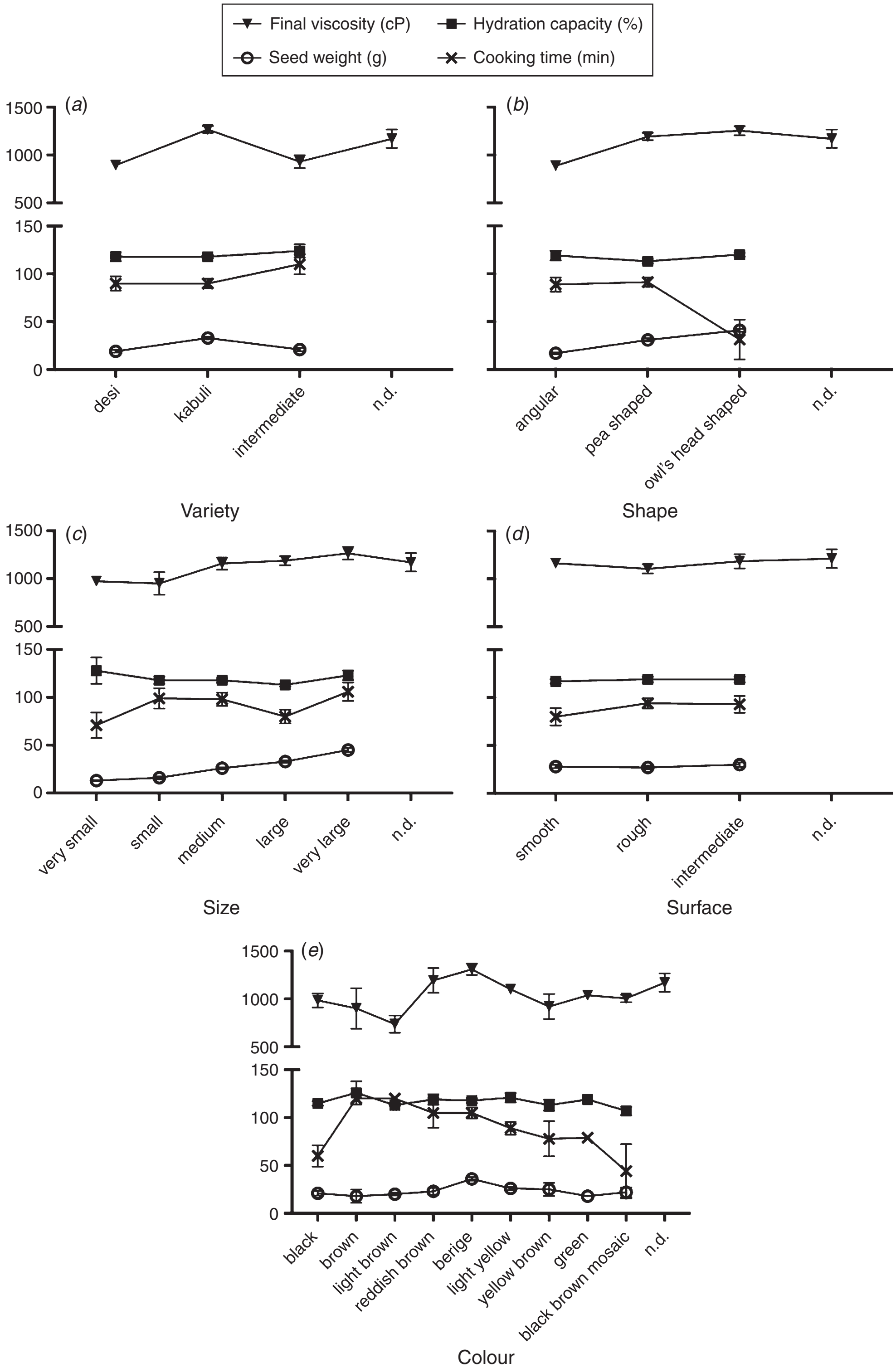

Fig. 2. Mean ± s.e. values of final viscosity, hydration capacity, seed weight and cooking time for chickpea germplasm collection for each class of seed (*a*) variety, (*b*) shape, (*c*) size, (*d*) surface and (*e*) colour.

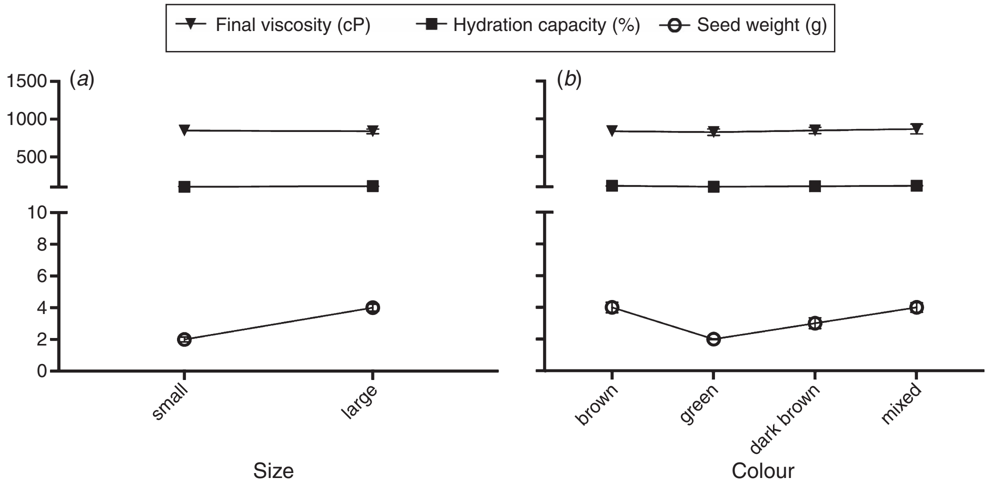

Fig. 3. Mean ± s.e. values of final viscosity, hydration capacity, seed weight and cooking time for lentil germplasm collection for each class of seed (*a*) size and (*b*) colour.

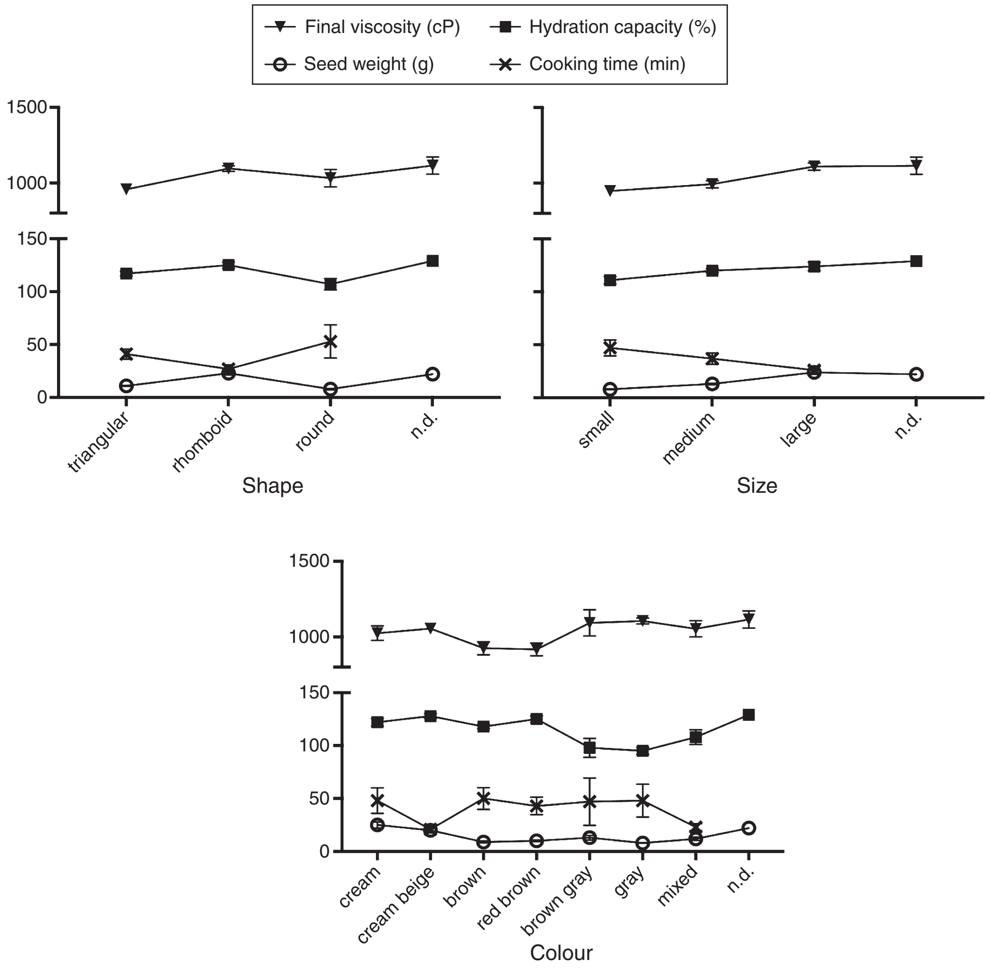

Fig. 4. Mean ± s.e. values of final viscosity, hydration capacity, seed weight and cooking time for grass pea germplasm collection for each class of seed (*a*) shape, (*b*) size and (*c*) colour.

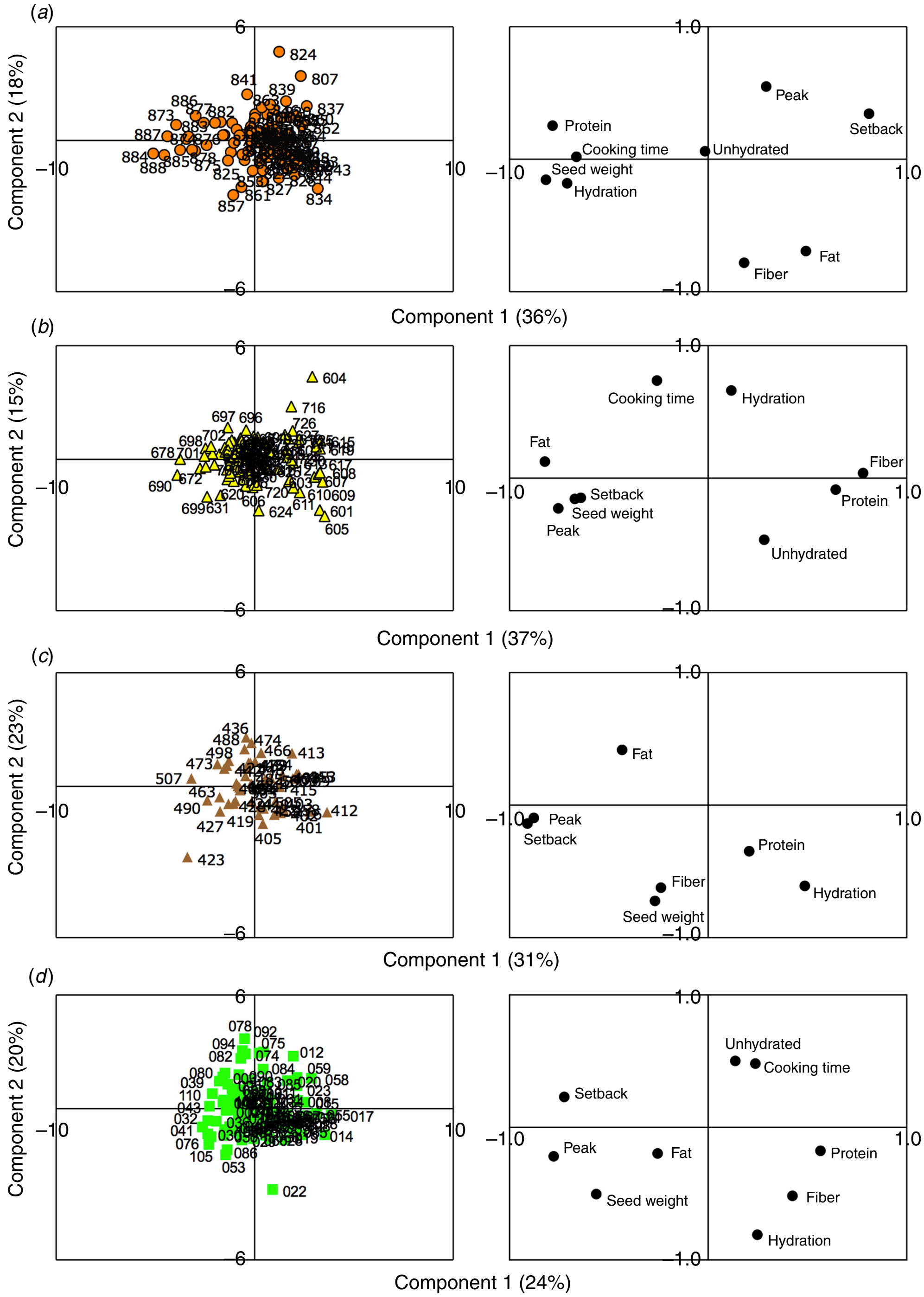

Fig. 5. Principal component analysis of score plot (left, with accession numbers) and loadings factors (right) for (*a*) faba bean, (*b*) chickpea, (*c*) lentil and (*d*) grass pea germplasm collections. Loading factors consisted of nine variables: peak, set back, cooking time, 100-seed weight, hydration capacity, unhydrated seeds, and contents of protein, fat and fibre. Note: the parameters cooking time and unhydrated seeds were not determined for lentil samples.

LEGCA608 and LEGCA609 had high values of protein and fibre content.

For the lentil germplasm collection, 54% of total variance was explained, corresponding to a first component of 31% and a second component of 23% (Fig. 5*c*). The viscosity parameters (peak and setback) appeared negatively correlated with protein content as well as hydration capacity (as already seen in Table 4). Hence, accession LEGLC423 could be isolated for its high fibre content and seed weight.

The grass pea PCA explained 44% of total variance, i.e. 24% (first component) and 20% (second component). Similar to observations for the lentil germplasm collection, and based on the first component, the viscosity parameters appeared negatively correlated with protein content and positively correlated with fat content and seed weight (Fig. 5*d*). Accession LEGLS022 separated from the rest of the group owing to its high 100-seed weight.

Conclusion

The results obtained in this study showed a high degree of variability between legume species for their pasting and cooking characteristics. With the exception of chickpea, seed weight was positively correlated with hydration capacity. Interestingly, in faba bean, no significant relation between seed traits and pasting properties and a negative correlation between final viscosity and cooking time was found, which is most important considering that the faba bean germplasm collection had the highest viscosity profiles.

In general, seed traits such as size, shape, colour, variety and surface type affected final viscosity, seed weight, hydration capacity and cooking time. Studying and understanding how these physico-chemical parameters vary with phenotypic and genotypic traits is important because they could be used as predicting factors for evaluation of germplasm cooking quality.

Longer cooking time can also be correlated with the chemical composition of seeds. It was possible to infer that cooking time was correlated with protein content in faba bean (which was also the legume with the highest seed weight), but in the other germplasm collections, protein and fibre content were more related to hydration capacity and percentage of unhydrated seeds.

In conclusion, taking into account the seed and flour characteristics mentioned above, the appropriate pulse can be selected, with higher viscosity profiles or lower cooking times, to substitute for cereal flours in development of, for example, pasta or noodles.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

The authors acknowledge funding from the European Union's Seventh Framework Program for research, technological development and demonstration under grant agreement no. FP7-613551, LEGATO project; the European Union's Horizon 2020 research and innovation program under grant agreement no. 727973, TRUE project; and National Funds from FCT through projects PEst-OE/EQB/LA0016/2013, UID/Multi/04551/2013 and IF/01337/2014.

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Appendix 1. Mean of peak, trough, breakdown, final viscosity (FV) setback, seed weight (SW), hydration capacity (HC), unhydrated seeds (US) and cooking time of the faba bean germplasm collection for each class of seed size and colour

Within column and seed trait, means followed by the same letter are not significantly different at $P = 0.05$; n.d., not determined

	Peak	Trough	Breakdown	FV	Setback	SW	HC	US	CT
			(cP)			(g)	(%)		(min)
				Size					
Very small (*n* = 3)	3033a	2952ab	81a	5074a	2123a	38a	80a	21a	27a
Small (*n* = 31)	2893a	2672ab	221ab	4340a	1668ab	69a	97b	22a	54a
Medium (*n* = 29)	3078a	2808a	271b	4428a	1620b	91b	105c	21a	67a
Large (*n* = 15)	2941a	2650b	291b	4099ab	1449bc	116c	114d	19a	76a
Very large (*n* = 8)	2763a	2476ab	288b	3593b	1117c	149d	117d	21a	117b
				Colour					
Brown (*n* = 11)	3068a	2864a	204a	4667a	1803a	78a	98a	20a	55a
Dark brown (*n* = 6)	3172a	3009a	162a	4854a	1844a	65a	100a	20a	41b
Dark green (*n* = 10)	2892a	2585a	307a	4092ab	1507a	92a	105a	22a	57c
Light brown (*n* = 32)	2974a	2725a	249a	4336a	1611a	92a	103a	21a	68d
Light green (*n* = 14)	2818a	2532a	286a	3684b	1152b	135b	119b	22a	116e
Mixed (*n* = 13)	2898a	2637a	261a	4259ab	1622a	76a	100a	19a	53f

Appendix 2. Mean of peak, trough, breakdown, final viscosity (FV), setback, seed weight (SW), hydration capacity (HC), unhydrated seeds (US) and cooking time of the chickpea germplasm collection for each class of seed variety, shape, size, surface and colour

Within column and seed trait, means followed by the same letter are not significantly different at $P = 0.05$; n.d., not determined

	Peak	Trough	Breakdown	FV	Setback	SW	HC	US	CT
			(cP)			(g)	(%)		(min)
				Variety					
Desi (*n* = 26)	712a	684a	28a	894a	210a	19a	118a	0a	90a
Kabuli (*n* = 50)	976b	914b	62b	1268b	354b	33b	118a	0a	90a
Intermediate (*n* = 3)	770ab	744ab	26ab	931ab	187ab	21ab	124a	1b	110a
n.d. (*n* = 7)	916b	878b	38ab	1171b	292ab	n.d.	n.d.	n.d	n.d.
				Shape					
Angular (*n* = 24)	709a	681a	28a	888a	207a	17a	119a	0a	89a
Pea shape (*n* = 15)	945b	894b	51ab	1194b	300a	31b	113a	0a	91a
Owl's-head shape (*n* = 40)	960b	287c	62b	1255b	87b	41c	120a	0a	31b
n.d. (*n* = 7)	916b	878b	38ab	1171b	292a	n.d.	n.d.	n.d.	n.d.
				Size					
Very small (*n* = 8)	782ab	754ab	28a	974a	220a	13a	128a	1a	71a
Small (*n* = 12)	734a	685a	49a	950a	265a	16a	118a	0b	99a
Medium (*n* = 23)	890a	844b	46a	1158a	314a	26b	118a	0b	98a
Large (*n* = 24)	940b	883b	57a	1188a	306a	33c	113a	0b	80a
Very large (*n* = 11)	966b	911b	55a	1266a	355a	45d	123a	0b	106a
n.d. (*n* = 7)	916a	878ab	38a	1171a	292a	n.d.	n.d.	n.d.	n.d.
				Surface					
Smooth (*n* = 16)	920a	881a	39a	1164a	283a	28a	117a	0a	80a
Rough (*n* = 48)	857a	805a	52a	1105a	300a	27a	119a	0a	94a
Intermediate (*n* = 15)	918a	866a	52a	1184a	318a	30a	119a	0a	93a
n.d. (*n* = 7)	941a	900a	41a	1212a	312a	n.d.	n.d.	n.d.	n.d.
				Colour					
Black (*n* = 12)	795a	748a	47a	984a	236a	21a	115a	0a	60a
Brown (*n* = 3)	684a	658ab	26a	901ab	244a	18ab	126a	0a	120ab
Light brown (*n* = 2)	615a	593ab	23a	738ab	145a	20ab	113a	0a	120ab
Reddish brown (*n* = 4)	893ab	852ab	40a	1193ab	341a	23ab	119a	0a	105ab
Beige (*n* = 27)	985b	919b	66a	1310b	391a	36b	118a	0a	105b
Light yellow (*n* = 25)	880ab	835ab	44a	1100ab	265a	26a	121a	0a	89ab
Yellow brown (*n* = 3)	734ab	709ab	25a	921ab	213a	25ab	113a	1b	78ab
Green (*n* = 1)	810ab	802ab	8a	1039ab	237a	18ab	119a	0a	79ab
Black brown mosaic (*n* = 2)	809ab	777ab	32a	1005ab	228a	22ab	107a	0a	44ab

Appendix 3. Mean of peak, trough, breakdown, final viscosity (FV, setback, seed weight (SW) and hydration capacity (HC) of lentil germplasm collection for each class of seed size and colour

Within column and seed trait, means followed by the same letter are not significantly different at $P = 0.05$; n.d., not determined

	Peak	Trough	Breakdown (cP)	FV	Setback	SW (g)	HC (%)
			Size				
Small (n =20)	570a	523a	47a	849a	326a	2a	105a
Large ($n = 27$)	589a	535a	53a	840a	305a	4b	114a
			Colour				
Brown ($n = 18$)	571a	532a	40a	838a	306a	4a	113a
Green ($n = 8$)	582a	529a	53ab	824a	294a	2b	102b
Dark brown ($n = 9$)	589a	539a	50ab	846a	307a	3ab	107ab
Mixed ($n = 12$)	588a	522a	66b	866a	344a	4a	115a

Appendix 4. Mean of peak, trough, breakdown, final viscosity (FV), setback, seed weight (SW), hydration capacity (HC), unhydrated seeds (US) and cooking time of the grass pea germplasm collection for each class of seed shape, size, and colour

Within column and seed trait, means followed by the same letter are not significantly different at $P = 0.05$; n.d., not determined

	Peak	Trough	Breakdown (cP)	FV	Setback	SW (g)	HC (%)	US	CT (min)
				Shape					
Triangular ($n = 54$)	571a	553a	18a	958a	405a	11a	117ab	7a	41a
Rhomboid ($n = 30$)	705b	681b	24a	1095b	414a	23b	125a	5a	27a
Round ($n = 9$)	587a	571a	16a	1032ab	461ab	8a	107b	10a	53a
n.d. ($n = 5$)	617ab	584ab	34a	1115ab	531b	22b	129ab	2a	n.d.
				Size					
Small ($n = 27$)	550a	534a	16a	949a	416ab	8a	111a	10a	47a
Medium ($n = 43$)	601a	583a	18ab	993a	410a	13b	120ab	6b	37a
Large ($n = 23$)	720b	693b	27b	1110b	417ab	24c	124b	5b	26a
n.d. ($n = 5$)	617ab	584ab	34ab	1115ab	531b	22c	129ab	2b	n.d.
				Colour					
Cream ($n = 9$)	683a	642ab	42a	1025a	383a	25a	122ad	4a	48a
Cream beige ($n = 27$)	666a	650a	17b	1055a	405ac	20ac	128a	5a	21a
Brown ($n = 16$)	561b	546b	15b	925a	379a	9b	118abd	7a	50a
Red brown ($n = 18$)	541b	524c	17b	917a	393a	10bc	125a	8a	43a
Brown grey ($n = 5$)	621a	601a	21ab	1093a	493abc	13bc	98bc	15b	47a
Grey ($n = 8$)	599a	581a	18b	1106a	525bc	8c	95c	10ab	48a
Mixed ($n = 10$)	650a	628a	22b	1053a	425ab	12b	108bcd	6a	23a
n.d. ($n = 5$)	617a	584a	34ab	1115a	531c	22a	129a	2a	n.d.