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# Evaluation of puffing quality of Australian desi chickpeas by different physical attributes.

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**Abstract**

Puffing involves roasting grains or legumes in hot sand without oil for a short time resulting in a popped type of healthy snack food. The aim of the present study was to understand the range of puffing ability of Australian desi chickpea genotypes. Calculations for puffing yield, expansion volume and puff size from the literature were applied to our samples. In addition, it was necessary to develop a new formula to measure the ratio of seed expansion without bias from puffing yield to compare the performance of our samples. This was necessary because their puffing yields were generally low relative to more established puffed products such as popcorn. Kyabra was identified as a superior puffing genotype (52% seeds puffed and 0.67-2.09 mL/g expansion volume), whilst Line 4 had the greatest seed expansion (0.62 mL/seed at 25 °C), but with a low puffing yield (7-11%). Storage temperature was investigated and cooler storage was found to generally hinder the puffing yield of chickpea. Australian chickpeas were found to have a range of puffing performance, which suggests that potential exists within the genetic pool to improve both the puffing yield and the expansion volume of seeds for this snack food market.

**Keywords**

grain legume; puffing yield; snack food; seed size; expansion volume

## 1. Introduction

Chickpeas (*Cicer arietinum* L.) are the second largest cultivated legume in the world (Varshney et al., 2013) and are available as small-seeded desi (brown-coloured with a wrinkled seed-coat) and bold-seeded kabuli (cream-colored with a smooth seed-coat). Chickpeas are processed in a variety of ways e.g. puffing, roasting, splitting, frying, canning, and boiling. Puffing of desi chickpeas has been practised for many years in the Indian sub-continent, Asia, Africa and the Middle East. Puffing whole chickpea seeds in sand is a traditional processing method in India, especially in the South. Puffing is a cooking method where whole chickpeas are popped in hot sand without oil, resulting in seeds with lower bulk density and improved flavour.

The literature on puffing is dominated by studies on cereals such as: rice (Mahanta & Bhattacharya, 2010), wheat (Fan, Hsieh, & Huff, 1999), sorghum (Singh & Srivastava, 1993), and corn (Pordesimo, Anantheswaran, Fleischmann, Lin, & Hanna, 1990). In contrast, there are few studies investigating chickpea puffing, despite widespread consumption of this product. The literature on chickpea puffing is scant and mainly examines Indian desi chickpea cultivars, with the latest one published in 2005 (Kaur, Singh, & Sodhi, 2005; Pratape & Kurien, 1986; Singh et al., 1992), but there are none on Australian desi chickpeas. It has been reported that bold seeded varieties of desi chickpeas with smooth surface are often preferred in India for roasting and puffing (Kaur et al., 2005). This rounder-shaped desi with a smooth seed coat is as also called a *gulabi*-type chickpea (Wood & Knights, 2003). The Australian chickpea breeding program does not currently select for *gulabi*-type chickpeas, nor do they evaluate puffing performance (Wood, personal communication).

Various terms are used in the literature to describe the relative proportion of puffed to unpuffed seeds. "Puffing yield" as reported in this study, focuses on the relative proportion of puffed seeds by count (Pratape & Kurien, 1986; Singh et al., 1992), whereas "percent hardshelled grains" puts the emphasis on the unpuffed seeds (Kaur et al., 2005). The two values are directly related as one can be determined from the other by subtracting from 100%. In terms of quality of product, unpuffed seeds are undesirable as they are hard to chew, and can be observed in a finished product due to seed coat retention and their somewhat darker colour. Therefore puffing yield is important from a consumer perspective as the presence of unpuffed seeds decreases the value and acceptability of the final product and high puffing yield is important for processors trying to maximise returns.

The present work evaluates the puffing ability ("puffability") of twelve Australian desi chickpea genotypes from a single trial. The goal was to understand the range in puffability of existing genetic material within the Australian breeding program. In order to evaluate puffability, various methods of puffing performance were measured according to methods in the existing literature. However, it became apparent that the existing calculations for expansion volume were not adequately capturing the actual increase in expansion on puffing due to bias by the puffing yield. Hence, we developed a new expansion volume calculation independent of yeld. Chickpea puffability can now be evaluated using two independent traits of puffing; puffing yield and expansion volume. In addition, the effect of two storage temperatures, 7.5 °C and 25 °C, on puffability was also examined.

## 2. Materials and methods

### *2.1. Materials*

Twelve Australian desi chickpea samples were sourced from the 2012 Coonamble National Variety Trial (NVT), Australia. They included eight breeding lines (Line 1 to Line 8) and four commercial varieties (Jimbour, PBA Boundary, PBA HatTrick, and Kyabra). Composite samples (of three field replicates) were evaluated for each genotype.

*2.2. Sample storage*

Chickpea samples were stored for one month in airtight PET jars in cycling temperature controlled cabinets (www.labec.com.au); half kept at 7.5 °C and the other half at 25 °C. Chickpeas stored at 7.5 °C temperature were transferred to the 25 °C temperature controlled cabinets 72 hours prior to the actual puffing experiments for temperature equalisation. The temperature of 25 °C was chosen as typical of "room temperature", whereas 7.5 °C was chosen as a low contrasting temperature used in similar studies in India (Pratape, V.M. personal communication).

*2.3. Physical properties of raw chickpea seeds*

Number, weight and seed size of raw chickpeas seeds (approx. 30 g) were recorded by manually counting, weighing 100 seed weights of raw chickpea seeds. Results are expressed as g/100 seeds. Seed volume was measured by placing seeds (approx. 30g) in a 100 mL graduated measuring cylinder and reading the height of seeds. These methods are prescribed by the International Seed Testing Association (ISTA, http://www.treeseedfa.org/uploaddocuments/IntroductiontoSeedTesting.pdf).

*2.4. Puffing process*

The puffing method (conducted in batches) was adapted from the method of Pratape and Kurien (1986) to obtain chickpea products with maximum expansion and minimal burning. This method follows the standard processing conditions for puffing chickpeas in India. Briefly, whole chickpea seeds (30 g) were heated to 140 °C in sand (chickpea: sand, 1:5 weight:weight) for 2 min in an open iron *kadai* (purchased from a local store in India) and then tempered (wrapped in a piece of cheesecloth) to equilibrate to room temperature for 100 min. The tempered seeds, held in a perforated strainer, were momentarily dipped in water at room temperature, drained and tipped into hot sand (230 °C) until the seeds started puffing and promptly removed to avoid burning. The distinct “pop” sound with characteristic puffed, roasted aroma at the final stage indicated that the chickpeas had been puffed successfully.

*2.5. Puffing quality traits*

As there was no clear criteria in the literature for distinguishing between puffed and unpuffed chickpeas, the following criteria was developed in this study to identify each successfully puffed seed within the sample: a puffed seed had a cracked or missing outer husk, with visible golden-yellow coloured cotyledon and an expanded volume. Visually determining expansion is challenging as some chickpea seeds may not expand greatly (see Section 3.2.1, below), although there is a visible crack in the outer husk. Figure 1 illustrates three examples of puffed chickpeas displaying variability in appearance following puffing.

After puffing, the puffed and unpuffed chickpea seeds were separated and counted. Volumes of puffed and unpuffed chickpeas were determined using 50 and 100 mL graduated measuring cylinder, respectively, and their respective weights and volumes recorded. All measurements were recorded in triplicate and then mean, standard deviations, puffing yield, puff size and expansion volume were calculated. The reduction in weight of chickpea seeds due to puffing was also calculated by subtracting the initial weight of raw seeds from the weight of puffed seeds.

*2.5.1. Puffing yield*

Puffing yield (%) provides a measure of the proportion of seeds that puff and is calculated as:

$$Puffing\ yield = \left(\frac{Final\ number\ of\ puffed\ seeds}{Number\ of\ total\ seeds}\right) \times 100$$ (Singh & Srivastava, 1993)

*2.5.2. Expansion volume*

Various measures of expansion volume (Sweley et al., 2012) have been reported in the literature for popcorn (Dofing et al., 1990; Pordesimo et al., 1990; Wu & Schwartzberg, 1992) and popped sorghum (Gupta, Srivastava, & Srivastava, 1995).

$$Expansion\ volume\ 1 = \left(\frac{Final\ volume\ of\ seeds\ after\ puffing\ (\text{mL})}{Initial\ volume\ of\ raw\ seeds\ (\text{mL})}\right)$$ (Wu & Schwartzberg, 1992)

where final volume of seeds after puffing is defined as the volume of all chickpeas (including puffed and unpuffed together) from the original 30 g sample.

$$Expansion\ volume\ 2\ = \left(\frac{Total\ puffed\ volume\ (mL)}{Weight\ of\ puffed\ seeds\ (g)}\right)$$ (Pordesimo et al., 1990)

where total puffed volume is defined as the volume of only puffed chickpeas, separated from the unpuffed seeds, and weight of puffed seeds is defined as the weight of the seeds that successfully puffed.

$$Expansion\ volume\ 3 = \left(\frac{Total\ puffed\ volume(mL)}{Original\ weight\ of\ raw\ seeds\ (g)}\right)$$ (Gupta et al., 1995)

where total puffed volume is defined as in the *Expansion volume* 2 calculation.

A new calculation for expansion volume is proposed below:

$$Expansion\ volume\ 4 = \frac{Total\ puffed\ volume\ (mL)}{(Puffing\ yield \times Initial\ volume\ of\ raw\ chickpeas\ (mL))}$$ or

$$Expansion\ volume\ 4 = \left(\frac{1}{Puffing\ yield} \times \frac{Total\ puffed\ volume\ (mL)}{Initial\ volume\ of\ raw\ chickpeas\ (mL)}\right)$$

where total puffed volume is defined as in the *Expansion volume* 2 calculation. The lower calculation allows statistical analysis of the first and second parts of the equation separately to avoid any trending of residuals which can occur with a very small denominator.

### *2.5.3. Puff size*

Puff size is adopted from the "flake size" measurement for popping of corn and is calculated as follows:

$$Puff\ size = \left(\frac{Total\ puffed\ volume\ (mL)}{Number\ of\ puffed\ seeds}\right)$$ (Pordesimo et al., 1990)

Where, total puffed volume is defined in the equation, *Expansion volume* 2, above.

## *2.6. Statistical analyses*

All analytical assessments were conducted in triplicate; results are expressed as mean ± one standard deviation (S.D.). Values given in tables and figures are the means of three determinations, unless otherwise stated. The statistical significance of differences among the genotypes and between the temperatures were evaluated by two-way analysis of variance (ANOVA) using the SPSS Statistical Software, version 20 (SPSS Inc., Chicago, Illinois, USA). Tukey's honestly significant difference (HSD) multiple comparison procedure was used to compare means at the 95% confidence level. The significance of the Pearson correlation coefficients was assessed at the 95% confidence level.

# **3. Results and Discussion**

## *3.1. Puffing yield*

### *3.1.1. Genotypic differences in puffing yield*

Puffing yields of twelve desi chickpea genotypes samples following storage at the two different temperatures are presented in Figure 2. Temperature effects on puffing yield are discussed separately (see below). Puffing yield data, averaged over temperature, are presented in Table 1, showing significant variation among the different genotypes investigated. The range in puffing yields of twelve Australian genotypes was 6-52% (Figure 2). Previous studies reported wide-ranging values for chickpea puffing yield: 62-68% (Pratape & Kurien, 1986), 42-57% (Singh et al., 1992); 2-100% (Rao, Satpute, & Bera, 1995); and 40-58% (Kaur et al., 2005). The results from this study can also be compared with a previous study evaluating the puffing properties of Indian and Australian desi chickpea genotypes (Paul Mukhopadhyay et al., 2012), in which none of the four Australian genotypes investigated showed any puffing ability.

For the puffing method used in this study, an acceptable puffing yield is 20% (Unpublished results, CFTRI, 2012), however higher yields are preferable. Figure 2 shows that Kyabra was clearly superior in terms of puffing yield, with 52% puffed seeds after storage at 25 °C. Four other genotypes (Line 2, Line 6, Line 3 and Line 7) had reasonable puffing yields of > 20%, again after storage at 25 °C. The worst performing genotypes were PBA Boundary and Line 1, with < 10% seeds puffed. Attempts were made to improve the puffing yield of the poorly performing genotypes, including incorporating a different kind of pre-treatment consisting of alternate moisture wetting and drying, however no substantial improvement in puffing yield was noted.

This study demonstrated significant variation in the puffing yield of these Australian chickpeas. Genetic influence on puffing yield has been previously reported in other countries (Pratape & Kurien, 1986; Singh et al., 1992) and Rao et al. (1995) calculated 95% heritability for this trait. This suggests that there is potential within the Australian desi chickpea genetic pool to breed new varieties with enhanced puffing ability.

*3.1.2. Effect of seed size on puffing yield*

Studies on puffing typically report 100 seed weight (or "seed weight") and 100 seed volume (or "seed volume") as part of the physical characterisation of chickpea seed size (Kaur et al., 2005; Rao et al., 1995; Singh et al., 1992). The related parameter, seed density, was found not to vary in this study (approx. 1.2 g/mL, data not shown). Seed weight varied from 18.9 g to 25.6 g (Figure 3). In previous studies, chickpea genotypes had seed weights of 12.6-31.4 g (6 varieties, (Singh et al., 1992)), 11.0-25.0 g (502 genotypes, (Rao et al., 1995)) and 12.5-16.8 g (5 cultivars, (Kaur et al., 2005)). It should be noted that in the study by Singh et al. (1992), one sample, called "local variety", had a seed weight of 31.4 g, while the remaining 5 varieties had seed weights in the range 12.6-14.3 g. Comparing our data to previous studies, Australian chickpeas have seed weights near the top of most reported ranges, and substantially greater than the most recent study by Kaur et al. (2005).

In terms of the effect of seed weight on puffing yield, conflicting results have been reported. Singh et al. (1992) found that the higher the seed weight, the higher the puffing yield. On the other hand, Kaur et al. (2005) found a negative relationship between the two parameters. In the present study, no trend was evident. However, all the genotypes that gave puffing yields of > 20% had seed weights ≥ 24 g/100 seeds. In contrast, one genotype, Line 5, had a seed weight of 25.6 g/100 seeds (the highest value) but had a puffing yield of only 13.9%. The conclusions of Singh et al. (1992) suggest that the seed size of all Australian genotypes should have led to acceptable puffing yields, but this was not observed. This suggests that there are aspects other than seed size that are influencing puffing yield of Australian genotypes. One possible related explanation is that Australian desi chickpeas have the traditional wrinkled angular seed shape, which is in contrast to smoother, rounder 'pea' seed shapes of *gulabi* types known to be preferred for puffing (Knights, Wood, & Harden, 2011). It is possible that the seed shape and associated contours of the seed coat or some other unknown attribute of *gulabi* types could play a role in higher puffing yields.

*3.1.3. Puffing yield following storage at 7.5 °C or 25 °C*

Storage temperature had a significant impact on the final puffing yield (Table 2) with up to seven of the genotypes negatively affected by storage at 7.5 °C (Figure 2). Of the six genotypes (Line 8, Line 2, Line 6, Line 3, Line 7 and Kyabra) that showed puffing yield at ≥ 20% after storage at 25 °C; only three out of them (Line 2, Line 3 and Kyabra) showed similar puffability after storage at 7.5 °C (Figure 2). Jimbour, Line 5 and Line 4 showed no significant differences in puffing yield after storage at either temperature. Kyabra was the best puffing genotype with 52% and 36% seeds puffed after storage at 25 °C and 7.5 °C, respectively. PBA Boundary and Line 1 displayed poor puffability, with less than 10% seeds puffed for both storage temperatures.

No previous studies (to the best of our knowledge) have investigated the effect of storage temperature on puffing yield and it is difficult to explain the results obtained in this work. Known factors that impact on puffing yield are moisture content (Sweley et al., 2013), protein and starch (both type and structure). Changes in moisture content may occur during storage, but in this study the chickpeas were stored in airtight containers in controlled humidity surroundings. It is possible that storage at 7.5 °C did result in adverse changes to protein and/or starch structure, but further analyses were beyond the scope of this study. Nevertheless, these results suggest that ambient temperature storage may be preferred for chickpeas that are to be puffed.

*3.2. Expansion Volume*

*3.2.1. Genotypic differences in expansion volume*

Expansion volume aims to give a quantitative evaluation of the quality of puffed products by relating the final volume to some other parameter, either weight (initial seed weight or final puffed weight) or initial volume of seeds. Much of the literature on puffing derives from studies on popcorn, and various equations for calculating expansion volume have been devised depending on the quality aspect of interest. Expansion volume 1, above, emphasises the change in volume on puffing by reporting expansion volume as the ratio of final volume to initial volume of the entire sample. Equation 2 relates puffed volume to puffed weight, and ignores any unpuffed sample, giving a measure of expansion volume that may be useful for packaged products where the product is sold by weight (Sweley et al., 2013). Equation 3 is the one most commonly found in the popcorn literature (Sweley et al., 2013) and is used for calculating final puffed volume compared to initial weight, useful where volume is the basis for sale (e.g. popcorn at movie theatres).

Expansion volumes calculated from equations 1-3 are given in Table 3 (where data for the two different storage temperatures are presented). Values for expansion volume 1 ranged from 1.02 (Line 4) to 1.18 (Kyabra) for chickpeas stored at 25 °C. These are low compared to previous reports in the literature where expansion volumes of around 1.5 (range 1.2 – 1.5) are found (Kaur et al., 2005; Rao et al., 1995; Unpublished results, CFTRI, 2012). Values for expansion volume 2 (Table 3, 25 °C) ranged from 1.91 mL/g (Line 3) to 2.95 mL/g (Line 4). Although proposed in 1990, expansion volumes calculated by equation 2 are rarely reported, however a recent study by Sweley et al. (2012), gives values of between 44 and 52 mL/g for popcorn hybrids. The considerable differences between chickpea expansion volume 2 and those of popcorn are due to the fact that chickpeas do not expand as much as popcorn kernels.

As noted above, expansion volume 3 is the most commonly quoted value to report puffing quality for popped corn and other cereals. Table 3 shows values for Australian chickpeas ranging from 0.17 mL/g (Line 1) to 1.02 mL/g (Kyabra) for a storage temperature of 25 °C. By way of comparison, a recent study on popcorn reports expansion volumes of 43-48 mL/g (Sweley et al., 2012). Two distinctions between popped corn and puffed chickpeas are noted. Firstly, by these existing calculations of expansion volume, there are large differences between chickpeas and popcorn. Secondly, equations 2 and 3 give similar results for popcorn (Sweley et al., 2012), whereas there are considerable differences between the values calculated for chickpeas. These differences can be traced to the low puffing yields of chickpeas, which increase the denominator in equation 3 relative to that in equation 2, due to the large number of unpuffed seeds.

The differences between chickpeas and other puffed products highlighted that puffing performance actually involves two independent traits, puffing yield and the actual expansion in seed size. Hence, we developed Equation 4 to capture the true expansion volume of seeds without any bias from unpuffed seeds. As can be seen in Table 3, expansion volume 4 values (25 °C storage) ranged from 1.36 (Line 3) to 1.97 (Line 4). It is now clear that some samples can have a high expansion volume even though only a small portion of the sample puffed. If ways could be found to increase the puffing yield of these lines, then they would be very good puffing varieties. In contrast, Kyabra had the highest puffing yield but its seeds did not expand in volume as much as many other samples examined in this study. The value of calculating expansion volume 4 thus, is to identify genotypes that have the greatest increase in volume due to puffing despite having a low puffing yield. This potential would have been missed through previously established calculations of expansion volume.

### *3.2.2. Effect of seed size on expansion volume*

Results of seed size of twelve Australian desi chickpeas and their individual expansion volumes are presented in Figure 3 and Table 3, respectively. Comparisons between these data and those in the literature can be made by considering the relationship between seed size and expansion volume 1. Analysis of the data presented by Singh et al. (1992) and Kaur et al. (2005) revealed no obvious trends between seed size and expansion volume 1. These results are consistent with the data reported in this study. The largest seeds are those of Line 5 and Line 7 (Figure 3) and these varieties have intermediate expansion volumes of 1.10 and 1.09, respectively (Table 3, 25 °C). Likewise the smallest seeds are those of PBA Boundary and Line 8, which have expansion volume 1 values of 1.05 and 1.09, respectively. Thus our data and previous reports in the literature indicate that seed size is not a good predictor of expansion volume 1, just as it was not a good predictor of puffing yield (above).

Expansion volume 4 considers only that portion of the seeds that have puffed and as such, it should be used to look for trends between seed size and expansion. Expansion volume 4 values for the largest seeds (Line 5 and Line 7) are 1.67 and 1.47, both intermediate. Expansion volumes 4 for the smallest seeds (PBA Boundary and Line 8) are 1.55 and 1.47, again intermediate. There is therefore no association between seed size and expansion volume 4. It may be concluded that seed size bears no relationship to expansion volume, no matter which way expansion volume is calculated.

*3.2.3. Expansion volume following storage at 7.5 °C or 25 °C*

Storage temperature had significant effects on expansion volumes of puffed chickpeas calculated using formulas for 1 and 3, but not 2 and 4 (Table 2). Using expansion volume 1, storage at 7.5 °C led to slightly higher results on average across the 12 genotypes (1.10 *cf* 1.08). On the other hand, using expansion volume 3, storage at 7.5 °C led to lower results on average. These results are only significant due to the bias of the percentage of seeds that puffed in the sample, since puffing yield itself is significantly different at the different storage temperatures. Thus there is no consistent effect of storage temperature on expansion volume. Genotype does seem to have an effect but is inconsistent (Table 3), which is why expansion volume 4 is not significantly different for storage temperature. Since storage temperature of seeds prior to puffing has little effect on expansion volume, ambient temperature storage is likely to be the preferred storage temperature, especially given the generally adverse effect of low temperature storage on puffing yield (above).

### *3.3. Puff size*

#### *3.3.1. Genotypic differences in puff size*

Puff size is a measure of the final average puffed volume for each seed that successfully puffed. This concept has been used to measure the "flake size" for popped corn (Pordesimo et al., 1990); we apply it for the first time to puffed chickpeas. Significant differences between some of the samples were observed for puff size but there was not a great deal of variability (Table 1). Puff size ranged from 0.39 mL/seed to 0.62 mL/seed ) after storage at 25 °C (Table 3). Kyabra was identified as a variety that had the highest puffing yield, yet the puff size of Kyabra was only intermediate at 0.49 mL/seed. The top performing genotypes in terms of puff size were Line 5, Jimbour and Line 4, but their puffing yields were low (Table 1).

Good puff size is important from the processing and consumer point of view as visually larger puffed chickpeas are assumed to have more air incorporated into their structure, leading desirable sensory properties. However, this is not always the case as puff size is biased by the initial seed size. Hence Equation 4 is a better measure of true expansion (without the bias of puffed yield or initial seed size) where higher values indicate puffed samples with lower densities and more desirable textures.

*3.3.2. Effect of seed size on puff size*

Seed size may be expected to influence puff size in that larger unpuffed seeds already are "ahead" of smaller ones. Comparing data in Table 3 (25 °C storage) and Figure 3, this holds true for Line 5, largest seed size and largest puff size and for PBA Boundary and Line 8 – smallest seed and puff sizes. However, in between the extremes, there is no relationship between seed size and puff size, although the variability in puff size was limited.

*3.3.3. Puff size following storage at 7.5 °C or 25 °C*

Storage temperatures did not have any significant effects on the puff size (Table 2). The mean puff sizes after storage at 7.5 °C and 25 °C were 0.48 and 0.49, respectively and were not significantly different for all the genotypes. In the absence of a significant temperature effect, storage at ambient temperature would appear to be preferential given the significant detrimental effect low temperature storage had on puffing yield (see above).

## 4. Conclusions

Puffing performance of Australian desi chickpeas ranged considerably in puffing yield, and to a lesser degree by expansion. Five of the twelve genotypes examined were found to give > 20% yield, and puffed successfully. The expansion volume equations in the literature were designed for cereals and underestimated the puffability of some Australian chickpea genotypes. Hence we developed a calculation of volume expansion (i.e. Equation 4), independent of puffing yield and initial seed size. By this equation, Line 4 at 25 °C was found to have a good expansion on puffing, almost doubling in volume, but had a low puffing yield. The effects of storage temperature on puffability were also examined. Low temperature

(7.5 °C) storage generally had a slight negative effect on puffing yield but no effect on the degree of expansion, hence ambient temperature storage of seed may be preferred.

This study has shown that there is potential to improve Australian desi chickpea qualities for commercial puffing by the traditional Indian method. As there was a wide variation in puffing yield from this single trial, future work should be aimed at better understanding the genetic and environmental contributions to this trait, as well as the potential physical and physiochemical mechanisms affecting both puffing yield and expansion volume.

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***List of tables***

Table 1

| Chickpea genotypes | Attributes | | | | | |
|---|---|---|---|---|---|---|
| | Puffing yield (%) | Expansion volume 1 | Expansion volume 2 (mL/g) | Expansion volume 3 (mL/g) | Expansion volume 4 | Puff size (mL/seed) |
| Line 1 | $7^{f}$ | $1.03^{e}$ | $2.41^{ab}$ | $0.15^{f}$ | $1.60^{ab}$ | $0.47^{ab}$ |
| Line 2 | $20^{bcd}$ | $1.12^{bc}$ | $1.88^{b}$ | $0.37^{bcd}$ | $1.36^{b}$ | $0.46^{b}$ |
| Line 3 | $27^{b}$ | $1.08^{bcde}$ | $1.99^{ab}$ | $0.50^{b}$ | $1.40^{b}$ | $0.49^{ab}$ |
| Line 4 | $9^{ef}$ | $1.03^{e}$ | $2.53^{ab}$ | $0.20^{ef}$ | $1.69^{ab}$ | $0.53^{ab}$ |
| Line 5 | $10^{ef}$ | $1.11^{bc}$ | $2.26^{ab}$ | $0.23^{def}$ | $1.76^{ab}$ | $0.6^{a}$ |
| Line 6 | $16^{cde}$ | $1.13^{ab}$ | $1.90^{b}$ | $0.31^{cde}$ | $1.42^{b}$ | $0.47^{ab}$ |
| Line 7 | $21^{bc}$ | $1.07^{cde}$ | $2.03^{ab}$ | $0.42^{bc}$ | $1.49^{b}$ | $0.52^{ab}$ |
| Line 8 | $12^{def}$ | $1.09^{bcd}$ | $2.33^{ab}$ | $0.26^{def}$ | $1.60^{ab}$ | $0.42^{b}$ |
| Jimbour | $10^{ef}$ | $1.12^{bc}$ | $2.73^{a}$ | $0.25^{def}$ | $1.95^{a}$ | $0.54^{ab}$ |
| Kyabra | $44^{a}$ | $1.18^{a}$ | $2.04^{ab}$ | $0.85^{a}$ | $1.40^{b}$ | $0.48^{ab}$ |
| PBA Boundary | $7^{f}$ | $1.04^{de}$ | $2.17^{ab}$ | $0.15^{f}$ | $1.50^{ab}$ | $0.43^{b}$ |
| PBA HatTrick | $14^{cde}$ | $1.10^{bc}$ | $219^{ab}$ | $29^{cdef}$ | $1.60^{ab}$ | $0.46^{b}$ |
| *P*-Value | 0.000 | 0.000 | 0.006 | 0.000 | 0.001 | 0.004 |
| Significance | ** | ** | ** | ** | ** | ** |

Genotypes with no letters in common within a column are significantly different at the 95% confidence level. *denotes significance of the attribute.

Table 2

| Attributes | Storage temperature (°C) | | $p$-value | Significance |
|---|---|---|---|---|
| | 7.5 | 25 | | |
| Puffing Yield (%) | 14[b] | 19[a] | 0.000 | ** |
| Expansion volume 1 | 1.10[a] | 1.08[b] | 0.003 | ** |
| Expansion volume 2 (mL/g) | 2.19 | 2.22 | 0.751 | |
| Expansion volume 3 (mL/g) | 0.28[b] | 0.38[a] | 0.000 | ** |
| Expansion volume 4 | 1.55 | 1.58 | 0.636 | |
| Puff size (mL/seed) | 0.48 | 0.49 | 0.509 | |

Attributes with no letters in common within a row are significantly different at the 95% confidence level. *denotes significance of the attribute.

Table 3

| Chickpea genotypes | Expansion volume 1 | | Expansion volume 2 (mL/g) | | Expansion volume 3 (mL/g) | | Expansion volume 4 | | Puff size (mL/seed) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 25 °C | 7.5 °C | 25 °C | 7.5 °C | 25 °C | 7.5 °C | 25 °C | 7.5 °C | 25 °C | 7.5 °C |
| Line 1 | 1.04±0.01 | 1.02±0.01 | 2.50±0.23 | 2.32±0.14 | 0.17±0.03 | 0.13±0.03 | 1.65±0.12 | 1.56±0.13 | 0.48±0.04 | 0.46±0.04 |
| Line 2 | 1.06±0.02 | 1.18±0.01 | 2.14±0.13 | 1.63±0.02 | 0.43±0.02 | 0.32±0.04 | 1.47±0.1 | 1.24±0.01 | 0.52±0.03 | 0.40±0.01 |
| Line 3 | 1.08±0.06 | 1.08±0.01 | 1.91±0.13 | 2.07±0.27 | 0.45±0.14 | 0.55±0.1 | 1.36±0.1 | 1.43±0.2 | 0.46±0.05 | 0.51±0.06 |
| Line 4 | 1.02±0.03 | 1.04±0.04 | 2.95±0.73 | 2.11±0.19 | 0.19±0.04 | 0.21±0.05 | 1.97±0.45 | 1.40±0.14 | 0.62±0.16 | 0.44±0.03 |
| Line 5 | 1.12±0.02 | 1.10±0.03 | 2.21±0.42 | 2.48±0.61 | 0.34±0.16 | 0.16±0.05 | 1.67±0.21 | 1.85±0.3 | 0.56±0.07 | 0.64±0.1 |
| Line 6 | 1.11±0.02 | 1.16±0.01 | 2.02± 0.05 | 1.77±0.12 | 0.43±0.06 | 0.20±0.07 | 1.48±0.04 | 1.37±0.16 | 0.48±0.01 | 0.45±0.05 |
| Line 7 | 1.06±0.01 | 1.09±0.04 | 2.02±0.1 | 2.03±0.18 | 0.55±0.14 | 0.29±0.07 | 1.47±0.11 | 1.51±0.1 | 0.53±0.01 | 0.50±0.03 |
| Line 8 | 1.09±0.04 | 1.09±0.01 | 2.15±0.14 | 2.51±0.53 | 0.38±0.08 | 0.14±0.07 | 1.47±0.11 | 1.73±0.4 | 0.39±0.03 | 0.44±0.1 |
| Jimbour | 1.14±0.05 | 1.09±0.04 | 2.36±0.16 | 3.11±1.19 | 0.25±0.08 | 0.24±0.08 | 1.81±0.1 | 2.09±0.68 | 0.49±0.05 | 0.60±0.21 |
| Kyabra | 1.18±0.05 | 1.18±0.04 | 2.09±0.05 | 1.99±0.13 | 1.02±0.19 | 0.67±0.05 | 1.40±0.06 | 1.39±0.1 | 0.49±0.01 | 0.47±0.05 |
| PBA Boundary | 1.03±0.03 | 1.05±0.05 | 2.20±0.19 | 2.14±0.19 | 0.19±0.04 | 0.12±0.07 | 1.55±0.15 | 1.46±0.24 | 0.44±0.06 | 0.43±0.07 |
| PBA HatTrick | 1.03±0.04 | 1.18±0.03 | 2.24±0.21 | 2.14±0.1 | 0.24±0.02 | 0.34±0.07 | 1.60±0.03 | 1.59±0.17 | 0.47±0.0 | 0.46±0.03 |

Results are expressed as means ± standard deviations

*List of figures*

**Figure 1.** Three puffed chickpeas: a poor puffing line, an intermediate puffing line and Kyabra, which puffed well (from left to right) showing the range of differences in puffing performance.

**Figure 2.** Puffing yield of Australian desi chickpeas after different storage temperature treatment.

The darker and the lighter columns indicate puffing yield after storage at 25 °C and 7.5 °C, respectively. Results are expressed as mean values based on triplicate observations; error bars are the standard deviation.

**Figure 3.** Seed size (100 seed weight) for twelve Australian desi chickpea genotypes.

Results are expressed as mean values based on triplicate measurements. Genotypes with no letters in common are significantly different at the 95% confidence level.



Figure 1

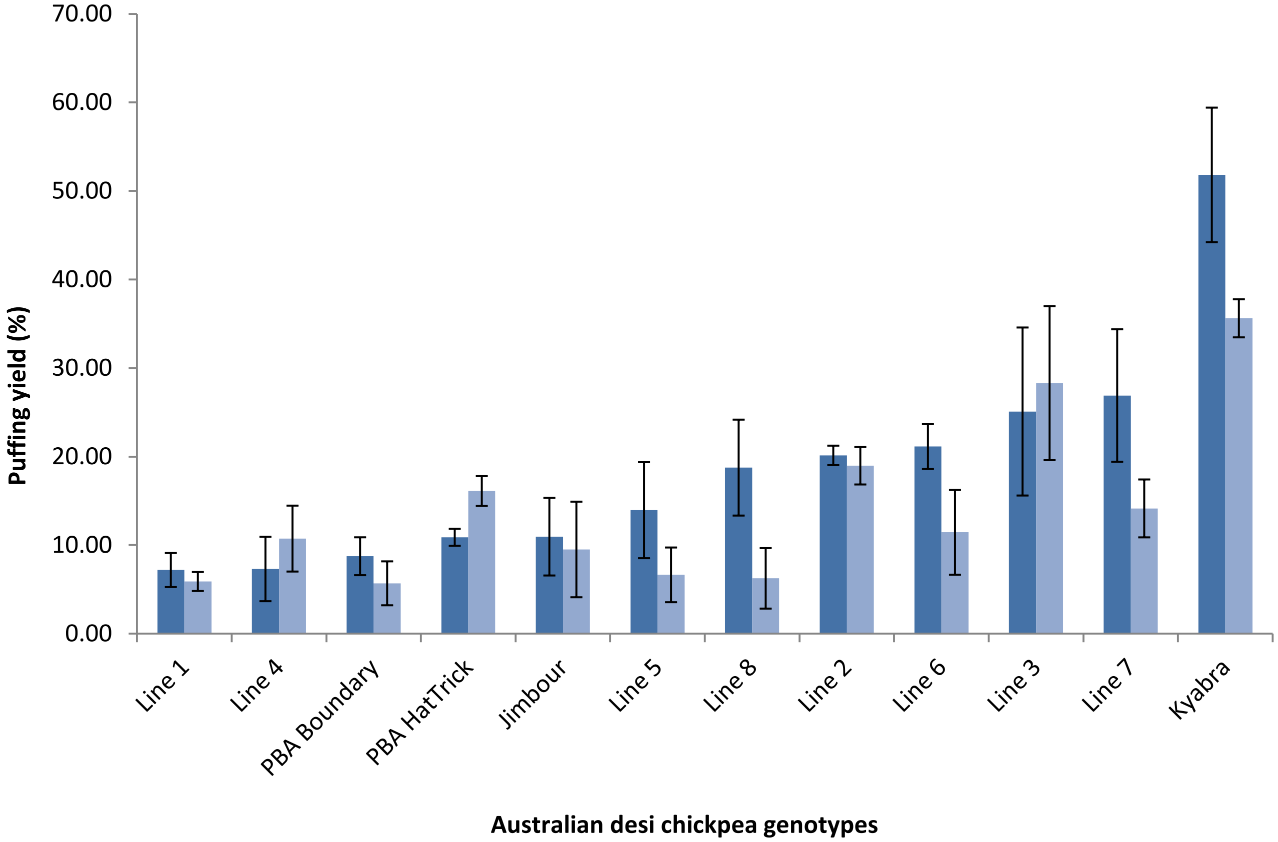
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Puffing yield (%)
Line 1
Line 4
PBA Boundary
PBA HatTrick
Jimbour
Line 5
Line 8
Line 2
Line 6
Line 3
Line 7
Kyabra
Australian desi chickpea genotypes

Figure 2

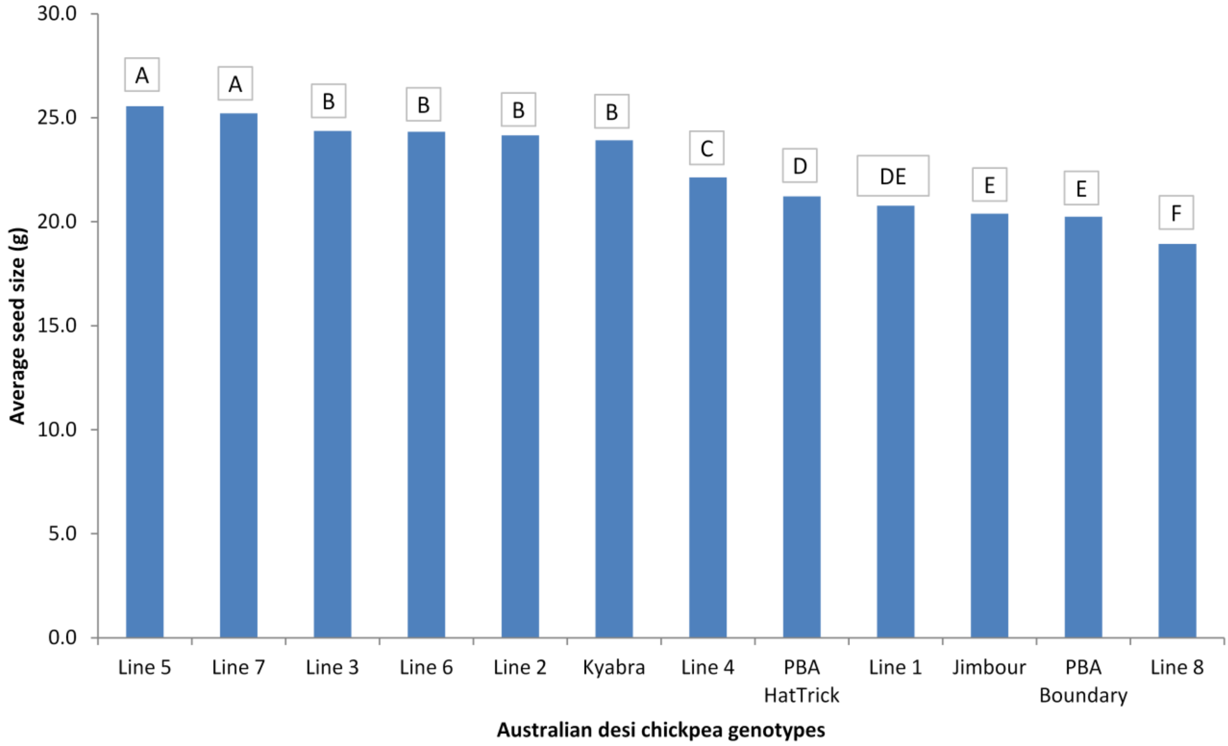
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Average seed size (g)
A
A
B
B
B
B
C
D
DE
E
E
F
Line 5
Line 7
Line 3
Line 6
Line 2
Kyabra
Line 4
PBA HatTrick
Line 1
Jimbour
PBA Boundary
Line 8
Australian desi chickpea genotypes

Figure 3