Assessment of malting characteristics of different Indian barley cultivars

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Abstract The impact of malting on composition and malt quality parameters such as diastatic power, α -amylase activity, β -amylase activity, hot water extract and β -glucan content were investigated in five different Indian barley cultivars. Protein content of grains increased significantly after malting. Soluble protein content of unmalted grain, which ranged from 3.20–3.93% increased after malting to 4.26–4.85%. Diastatic power of mature grain varied across genotype and their level increased (58.98–81.05 to 115.93–142.45 DP°) after malting. Diastatic power correlated very strongly with protein content ($r = 0.90$) and strongly with β -amylase activity ($r = 0.74$). α -amylase, which was low (0.042–0.189 Ceralpha Unit/g) initially in unmalted grain, was synthesized during germination to the range of 149.42–223.78 Ceralpha Unit/g. The correlation between diastatic power and α -amylase was very weak ($r = -0.04$). The levels of β -amylase in unmalted grain was in the range of 13.97–18.26; that amount got reduced after malting to 12.55–15.97 Betamyl-3 U/g. β -amylase had a strong positive correlation ($r = 0.85$) with grain protein. Malted grain which had higher protein content showed very strong negative correlation ($r = -0.86$) with hot water extract value. β -glucan content reduced 70–80% from the initial level, across genotypes.

Keywords Malt · Diastatic power · β -Amylase · α -Amylase · β -Glucan

Introduction

Barley (*Hordeum vulgare*) is an ancient and important cereal crop that is produced in climates ranging from sub-Arctic to subtropical and is considered as a poor man's crop in India. Its low input requirements and better adaptability to harsh environmental conditions such as drought, salinity, alkalinity and marginal land makes it important livelihood (Verma et al. 2008). Currently India produces 1,830,000 ton of barley (FAO 2014) and annual expected growth rate of barley is increasing at the rate 10% per year for industrial uses. Nearly 20–25% of its production is utilized by the malting industry (Verma et al. 2008). From there the malt is further supplied to the brewing industry (about 60%), malt whiskies (8–10%), energy drinks and baby foods (25%), while $\sim 7\%$ is used in medicinal syrups and vinegar (Verma et al. 2008).

Malting is a process applied to cereal grains, in which the grains are made to germinate under specific conditions up to the point of grain modification and then quickly dried to check further changes. Malting of barley grains is the keystone of the brewing and distilling industries (Jones 2005). For a successful mash, a good quality malt is always required by brewers. The effect of controlled malting on several components and enzymes within the barley grain determines the final quality of malt. Hydrolysis of starch through enzymes is a process fundamental to mashing and germination. Starch hydrolysis is a very complex process, highly regulated and as yet, not fully elucidated (Kotting et al. 2010).

Diastatic power is an important indicator of good quality malt and is defined by the total concentration of starch degrading enzymes present in the malt (Arends et al. 1995). Primarily, the activity of four enzymes (α -amylase, β -amylase, limit dextrinase and α -glucosidase) is important

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during malting and mashing, which hydrolyzes the starch into simple sugars (Qi et al. 2006). Variation in diastatic power of malt is affected by complex interaction of genetic variation and environmental factors (Arends et al. 1995). β -amylase is considered as the most important enzyme responsible for diastatic power (Arends et al. 1995). α -amylase enzyme is synthesized during germination by mature aleurone layers of barley and typically, its level increases after third day germination. However, its importance in diastatic power of the grain is less than that of β -amylase (Georg-Kraemer et al. 2001). β -amylase activity can be used as a screening criterion to select the barley variety that is suitable for malting (Gibson et al. 1995). At the moment, scientific findings related to the malt quality parameters developed in different Indian barley cultivars after germination is scanty. Therefore, the present work was undertaken to evaluate the malting potentials of different Indian barley cultivars and also to establish their relation with other malt quality attributes developed after germination.

Materials and methods

Procurement of raw materials

Five different barley cultivars viz. DWRB101, DWRUB52, DWRB73, DWRB91 and DWRB92 grown in the year 2016, were collected from Indian Institute of Wheat and Barley Research, Karnal, Haryana. The grains were cleaned and stored in gunny bags below 8 °C until when needed. All the chemicals used for chemical analysis were of analytical grade and obtained from Central Drug House, New Delhi. Enzyme estimation kit was supplied by Megazyme International Ireland, Bray, Ireland.

Malt preparation

The barley grains were steeped in tap water at 18 °C for 24 h, with change of water at 4 h intervals. After steeping, the excess water was drained and the grains spread evenly in a tray layered with wet cotton cloth. After covering the grains with a wet muslin cloth, the trays were placed in a laboratory incubator (Model BST-BOD/280, Bionics India) previously set at 18 °C for germination and germinated for 4 days. Formaldehyde solution (0.1%) was sprinkled over the wet cloth at 4 h intervals to prevent surface evaporation and mold growth. After the first 24 h, the grains were turned carefully twice daily to prevent matting. The germinated grains were kilned in a tray dryer at 50 °C for 20 h. The roots and shoots of the dry germinated grains were removed manually by rubbing between the palms.

The malts were stored in deep freezer at − 4 °C until analysis.

Protein, soluble protein and hot water extract content assay

Protein, soluble protein and malted grains hot water extract content of the different cultivars were determined by near infrared transmittance (Yin et al. 2002) (Model 1241, FOSS Co. Denmark). Two hundred g sample were weighed and placed in sample holding chamber of the instrument and malt analysis program was run. Results were recorded and expressed on dry matter basis.

Diastatic power

Grains samples were ground in a Tecator Cyclotec sample mill (Model Cyclotec 1093, FOSS Denmark) such that they can pass through a 0.5 mm screen. Diastatic power of unmalted as well as malted grains was measured using ASBC (2011) malt method No. 6. Reducing sugar was measured by the ferricyanide method and diastatic power was expressed as diastatic power degrees (DP°) on dry matter basis.

Alpha-amylase assay

α -amylase activity was determined in triplicate for both unmalted and malted grain, using Ceralpha assay (Megazyme Ireland Ltd.) as previously described by McCleary and Sheehan (1987). One unit of activity is defined as the amount of enzyme, in the presence of excess thermostable α -glucosidase, required to release one micromole of p-nitrophenol from p-Nitrophenyl- α -D-maltoheptaoside (BPNG7) in 1 min under the defined assay conditions and is termed a Ceralpha[®] Unit.

Beta-amylase assay

β -amylase activity was assayed using Betamyl assay (Megazyme Ireland Ltd.) as described by McCleary and Codd (1989). To release bound β -amylase, cysteine was added to extraction buffer. One unit of enzyme activity is defined as the amount of enzyme, in the presence of excess thermostable β -glucosidase, required to release one micromole of p-nitrophenol from p-Nitrophenyl- β -D-maltotrioside (PNP β -G3) in 1 min under the defined assay conditions and is termed a Betamyl-3[®] Unit.

Beta-glucan assay

Mixed linkage (1 → 3, 1 → 4)- β -D-glucan or commonly known as β -glucan was measured using Megazyme

(Megazyme Ireland Ltd.) assay kit, following the method described by McCleary and Nurthen (1986). Samples were suspended and hydrated in a buffer solution of pH 6.5 and then incubated with purified lichenase enzyme and filtered. An aliquot of the filtrate was then hydrolysed to completion with purified β -glucosidase. The D-glucose produced was assayed using a glucose oxidase/peroxidase reagent. The results are expressed as β -glucan per cent on dry weight basis.

Statistical analysis

ANOVA and least significant difference test for multiple comparison of means were performed with the SAS 9.3 software, using PROC GLM and LSMEANS/TUKEY adjustment statement, respectively. Correlation was established using Microsoft Excel 2013 version.

Results and discussion

Protein content

The protein contents of different barley cultivars, of both unmalted and malted grain, are presented in Fig. 1a. Table 1 details the analysis of variance of the malt quality parameters. Protein content was found in the range of 9.80–13.17% for unmalted grains, which increased significantly ($P < 0.05$) after malting to 10.90–13.33% among the different cultivars. Before malting, variety DWRUB52 had the least protein content, while variety DWRB92 had the most. Similarly, among the malted grains, variety DWRUB52 showed the lowest and DWRB92, highest protein content. Warle et al. (2015) reported similar changes in protein content of barley grain during germination. Kindiki et al. (2015) found that protein content of pearl millet (*Pennisetum glaucum*) increased significantly during germination followed by 24 h fermentation up to period of 5 days at different temperatures. This increase in protein content in germinated grain may be due to protein synthesis (Fasasi 2009). In contrast, Malleshi and Desikachar (1986) reported that after germination there was slight decrease in crude protein content in germinated grains due to transfer of nitrogenous material in growing embryo. Roots and shoots developed in malted barley reportedly contain hydrolyzed protein, which can be directly correlated with malting loss (Agu 2003). In the present study, the increase in total concentration of different amylolytic enzymes after germination may also have contributed to increase in protein content. The higher values of crude protein in grain after malting may be mainly due to reduction in moisture level, with subsequent

increase in total solids and loss of carbohydrate by roots and shoots.

Soluble protein

Figure 1b presents the values of the soluble protein content measured for the different barley varieties before and after malting. Soluble protein content increased significantly ($P < 0.05$) after malting in all cultivars. Among all cultivars, DWRB92 malt had the highest soluble protein content (4.86%), while DWRB101 malt had the lowest (4.26%). As a result of the malting process, there is an increase in enzyme activity which results in formation of higher amount of soluble protein and small peptides (Hoseney 1994). There could be at least 42 different active proteases within the grain during germination, as reported by Zhang and Jones (1995). Four classes of proteinases namely, cysteine, serine, aspartic and metallo, have been identified in barley. Cysteine class proteases play a key role in the degradation of storage proteins, making them very important to the production of high quality malt (Jones 2005). Bhatti (1996) found that germination resulted in extensive hydrolysis of protein, leading to high soluble to total protein ratio (Kolbach index) in barley malt. Soluble nitrogen produced as a result of proteolysis is utilized for synthesis of different enzymes, which are required for metabolism of carbohydrate reserves (Palmer 1989). Barley malt germinated at lower temperatures (17 °C) resulted in higher soluble nitrogen content than when germinated at higher temperature (20 °C) and the maximum hydrolysis occurred during the first 2 days (Agu and Palmer 1997).

Diastatic power

Diastatic power of barley grain is described by the activity of total starch converting enzymes presents in it (Georg-Kraemer et al. 2001). The diastatic power measured for both unmalted as well as malted grain is presented in Fig. 1c. The diastatic power of the different cultivars increased significantly after malting. DWRB92 had the highest value both in unmalted (81.05 DP°) and malted (142.45 DP°) grains, while DWRB101 showed lowest diastatic power among all varieties. Different varieties of unmalted grain also showed some diastatic power (58.98–81.05 DP°), which may be due to the presence of free β -amylase enzyme in mature resting grain. β -amylase enzyme is synthesized during grain development and appears in mature grain both in the free and the bound forms (Evans et al. 1997; Yin et al. 2002). Malted barley showed a strong positive correlation between diastatic power and protein content ($r = 0.90$) (Table 2). Similar results have been reported by several researchers (Swanston 1980; Arends et al. 1995). Very weak negative

Fig. 1 Malting characteristics of different Indian barley cultivars. **a** Protein content, **b** soluble protein, **c** diastatic power, **d** α -amylase activity, **e** β -amylase activity, **f** β -glucan content. [Solid bar] = unmalted grain; [Patterned bar] = malted grain. Mean $\pm$ SE ($n = 3$); values with similar

superscripts (a, b, c, d among varieties and A, B within variety) do not differ significantly ($P > 0.05$)

correlation was found between α -amylase and diastatic power ($r = -0.04$), but the relation with β -amylase was strongly positive ($r = 0.74$) (Table 2). This corroborates the previous findings that β -amylase is the main principal enzyme which is responsible for diastatic power (Gibson et al. 1995; Georg-Kraemer et al. 2001). The increase in

diastatic power of all malted grain is due to the conversion of the bound form of β -amylase to the active free state through proteolytic cleavage which occurred during grain germination (Guerin et al. 1992; Georg-Kraemer et al. 2001). Arends et al. (1995) reported that variation in diastatic power of barley is also affected by complex

Table 1 Analysis of variance of malt quality parameters of different barley cultivars

Dependent variable	Source of variance	df	Sum of squares	Mean square	F value	Pr > F
Protein	Model	9	29.35	3.26	78.28**	< 0.0001
	Error	20	0.83	0.04		
	Corrected total	29	30.19			
Soluble protein	Model	9	7.87	0.87	42.29**	< 0.0001
	Error	20	0.41	0.02		
	Corrected total	29	8.28			
Diastatic power	Model	9	28,267.79	3140.87	1061.77**	< 0.0001
	Error	20	59.16	2.96		
	Corrected total	29	28,326.95			
α -amylase	Model	9	242,943.05	26,993.67	1196.67**	< 0.0001
	Error	20	451.15	22.56		
	Corrected total	29	243,394.20			
β -amylase	Model	9	83.37	9.26	18.62**	< 0.0001
	Error	20	9.95	0.50		
	Corrected total	29	93.33			
Hot water extract	Model	4	2.97	0.74	84.12**	< 0.0001
	Error	10	0.09	0.01		
	Corrected total	14	3.06			
β -glucan	Model	9	114.68	12.74	751.19**	< 0.0001
	Error	20	0.34	0.02		
	Corrected total	29	115.01			

Significant at $P \leq 0.05$ **Table 2 Correlation coefficient matrix for diastatic power and other malt quality parameters of different malted barley cultivars

	Correlation coefficient r (n = 25)				
	Diastatic power	α -amylase	β -amylase	Protein	Hot water extract
Diastatic power	1.00				
α -amylase	– 0.04	1.00			
β -amylase	0.74	0.12	1.00		
Protein	0.90*	– 0.14	0.85	1.00	
Hot water extract	– 0.64	0.03	– 0.61	– 0.86	1.00

*Significant at $P < 0.05$

interaction between the different amylases enzymes and other malting and brewing parameters.

Alpha-amylase activity

α -amylase is important during grain germination, as it is one of the only known enzymes to be present in germinating barley grains that can initiate native starch hydrolysis (Georg-Kraemer et al. 2001). The α -amylase activity of different barley cultivars measured before and after malting for 4 days is presented in Fig. 1d. Unmalted grains showed very little or negligible α -amylase activities that varied from 0.042 Ceralpha Unit/g for DWRB92 to 0.189 Ceralpha Unit/g for DWRB91. However after germination all cultivars had higher α -amylase activity, which

differed significantly ($P < 0.05$) from each other, except for DWRUB52 and DWRB92. The highest value of α -amylase activity observed in malted barley was for DWRB91 (223.780 Ceralpha Unit/g) and the lowest for DWRB92 (149.42 Ceralpha Unit/g). There was a negative correlation ($r = -0.14$) between α -amylase activity and grain protein content and also α -amylase activity with diastatic power ($r = -0.04$) (Table 2). The reason for higher α -amylase activity in malted grain was its synthesis during grain germination under the control of gibberelins hormones (Chandler et al. (1984), in contrast to grain development, as for β -amylase (Arends et al. 1995; Georg-Kraemer et al. 2001). Briggs (1992) reported that α -amylase synthesis occurs only after endogenous synthesis of gibberellins in early germination from barley embryos. The

larger variation of α -amylase activity observed in different cultivars indicates that differences in their genotypes is the main source of variation among them (Gothard 1974; Arends et al. 1995).

Beta-amylase activity

The β -amylase enzyme activity of the five different barley cultivars is presented in Fig. 1e. After malting, the β -amylase enzyme activities decreased in all the cultivars, with significant ($P < 0.05$) reduction observed only in two of them (DWRB101 and DWRB920). The β -amylase enzyme activity ranged from 13.97 Betamyl-3 U/g for DWRUB52 to 18.26 Betamyl-3 U/g for DWRB92 in unmalted resting grain, while the corresponding values were 12.55 Betamyl-3 U/g for DWRUB52 and 15.97 Betamyl-3 U/g for DWRB92. Although the cultivar DWRB92 showed highest β -amylase enzyme activity, this was not true for its α -amylase activity. Cultivar DWRUB52, which showed lowest β -amylase activity had higher α -amylase activity than DWRB92. β -amylase is one of the most important components of the diastatic power of malt as there is a strong correlation ($r = 0.74$) observed between the levels of β -amylase activity in a malt and its diastatic power (Table 2). Very strong correlation ($r = 0.85$) was also found between protein content of grain and β -amylase activity, which agrees with previous reports by Swanston (1980) and Arends et al. (1995). However, the correlation between β -amylase and α -amylase activities was very weak ($r = 0.12$). Nitrogen application on soil during barley grain development results in increasing protein content of barley, which may have led to higher β -amylase after germination (Giese and Hopp 1984; Yin et al. 2002). Arends et al. (1995) explained that the strong correlation between grain protein and β -amylase content was because the same factors influence the production of β -amylase during grain filling and the synthesis of others proteins in endosperm of barley. During germination bound β -amylase is released as active form due to proteolytic cleavage. In the present study, the decrease in β -amylase activities after germination was probably due to the heat labile nature of β -amylase, which gets destroyed during kilning stage. Evans et al. (1997) reported that 20–36% of β -amylase activity of a green malt was reduced after kilning.

β -glucan content

Mixed linkage (1-3, 1-4)- β -D-glucan, commonly referred to as β -glucan is the major constituent of barley endosperm cell walls, comprising approximately 75% of it, in addition to arabinoxylan, the minor constituent, ~ 20% (Fincher and Stone 1986; Henry 1987). Barley contains

approximately 2–10% β -glucan of its total grain weight (Henry 1987). The different levels of β -glucan before and after malting in various barley varieties observed in this study are presented in Fig. 1f. Among the five cultivars DWRB91 and DWRB92 showed lowest and highest values at 4.16 and 5.76%, respectively, before malting. After malting, the β -glucan level significantly ($P < 0.05$) reduced in all cultivars but to different extents. In malt, levels of β -glucan ranged from 0.84% for DWRB101 to 1.72% for DWRB92. The percent reduction varied between different cultivars. The highest reduction observed was 80.77% for DWRB101, while the lowest of 70.13% was observed for DWRB92. The reduction of β -glucan levels after malting is due to the increased activity of β -(1-3), (1-4)-glucan-4-glucanhydrolase (EC 3.2.1.73) or β -glucanase enzyme, during germination. This enzyme is synthesized during germination and hydrolyzes β -glucan (Fox 2009). The hydrolysis of β -glucan during germination is important for malt producers, as it is closely associated with final malt yield and quality, as reported by Stuart et al. (1988).

Hot water extract

Extractable solid in wort from malt during mashing is known as hot water extract and it is one of the key parameters for selection of good quality malt. The hot water extract percentage of the different barley malt varieties is presented in Fig. 2. DWRUB52 malt had the highest hot water extract value (73.12%) and DWRB92, the lowest (71.82%). Although the correlation (Table 2) between hot water extract and α -amylase activity was very weak ($r = 0.03$), there was strong to very strong negative correlation between hot water extract and diastatic power ($r = -0.64$) and grain protein content ($r = -0.86$). Similar negative correlation between diastatic power and

Fig. 2 Hot water extract (HWE) of different varieties barley malt. Mean $\pm$ SEM ($n = 3$); values with similar superscripts (a, b, c, d, e) do not differ significantly ($P > 0.05$)

hot water extract was observed by Arends et al. (1995), who reported that high starch content in barley was associated with low protein content and higher extract value in brewing. The relation between grain protein and hot water extract is consistent with previous studies carried out by different authors (Rutger et al. 1967; Arends et al. 1995).

Conclusion

Malt was prepared from five different barley cultivars. Soluble protein content increased significantly after malting in all varieties, whereas the reverse was observed for cell wall β -glucan degradation. Malted grain, which is generally rich in nitrogenous compounds, exhibited higher amount of β -amylase enzyme activity. β -amylase enzyme comes out as a principal factor responsible for higher level of grain diastatic power. Mature unmalted grains also showed some diastatic power due to presence free β -amylase. Malted grain contained lower quantity of the heat-labile β -amylase. The level of α -amylase, which is synthesized mainly during germination varied across genotype. Production of high diastatic barley malt was accompanied by lower hot water extract value in the different cultivars. Barley of high diastatic power can be used as an adjunct in mashing, where unmalted cereal starch is present in grist.

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References

- Agu RC (2003) Some relationships between malted barleys of different nitrogen levels and the wort properties. *J Inst Brew* 109(2):106–109
- Agu RC, Palmer GH (1997) The effect of temperature on the modification of sorghum and barley during malting. *Process Biochem* 32(6):501–507
- Arends AM, Fox GP, Henry RJ, Marschke RJ, Symons MH (1995) Genetic and environmental variation in the diastatic power of Australian barley. *J Cereal Sci* 21(1):63–70
- ASBC (2011) American society of brewing chemists, methods of analysis, malt 6. Diastatic Power, St. Paul
- Bhatty RS (1996) Production of food malt from hull-less barley. *Cereal Chem* 73(1):75–80
- Briggs DE (1992) In: Shewry PR (ed) Barley: genetics, biochemistry, molecular biology and biotechnology. CAB International, Wallingford, p 369
- Chandler PM, Zwar JA, Jacobsen JV, Higgins TJ, Inglis AS (1984) The effects of gibberellic acid and abscisic acid on α -amylase mRNA levels in barley aleurone layers studies using an α -amylase cDNA clone. *Plant Mol Biol* 3(6):407–418
- Evans DE, MacLeod LC, Eglinton JK, Gibson CE, Zhang X, Wallace W, Skerritt JH, Lance RCM (1997) Measurement of Beta-amylase in malting barley (*Hordeum Vulgare* L.). I. Development of a quantitative ELISA for Beta-amylase. *J Cereal Sci* 26(2):229–239
- FAO (2014). <http://faostat.fao.org>. Accessed 24th May 2017
- Fasasi OS (2009) Proximate, antinutritional and functional properties of processed pearl millet (*Pennisetum glaucum*). *J Food Technol* 7(3):92–97
- Fincher GB, Stone BA (1986) Cell walls and their components in cereal grain technology. In: Pommaranz Y (ed) Advances in cereal science and technology, vol 8. American Association of Cereal Chemists Inc., St Paul, pp 207–295
- Fox GP (2009) Chemical composition in barley grains and malt quality. In: Zhang G, Li C (eds) Genetics and improvement of barley malt quality. Springer, Berlin, pp 63–98
- Georg-Kraemer JE, Mundstock EC, Cavalli-Molina S (2001) Developmental expression of amylases during barley malting. *J Cereal Sci* 33(3):279–288
- Gibson TS, Solah V, Holmes MG, Taylor HR (1995) Diastatic power in malted barley: contributions of malt parameters to its development and the potential of barley grain beta-amylase to predict malt diastatic power. *J Inst Brew* 101(4):277–280
- Giese H, Hopp HE (1984) Influence of nitrogen nutrition on the amount of hordein, protein Z and β -amylase messenger RNA in developing endosperms of barley. *Carlsberg Res Commun* 49(3):365
- Gothard PG (1974) Screening of barley varieties for alpha-amylase content. *J Inst Brew* 80(4):387–390
- Guerin JR, Lance RCM, Wallace W (1992) Release and activation of barley beta-amylase by malt endopeptidases. *J Cereal Sci* 15(1):5–14
- Henry RJ (1987) Pentosan and (1 $\rightarrow$ 3), (1 $\rightarrow$ 4)- β -glucan concentrations in endosperm and wholegrain of wheat, barley, oats and rye. *J Cereal Sci* 6(3):253–258
- Hoseney RC (1994) Principles of cereal science and technology, 2nd edn. American Association of Cereal Chemists (AACC), Eagan, pp 179–182
- Jones BL (2005) Endoproteases of barley and malt. *J Cereal Sci* 42(2):139–156
- Kindiki MM, Onyango A, Kyalo F (2015) Effects of processing on nutritional and sensory quality of pearl millet flour. *Food Sci Qual Manag* 42:13–19
- Kotting O, Kossmann J, Zeeman SC, Lloyd JR (2010) Regulation of starch metabolism: the age of enlightenment? *Curr Opin Plant Biol* 13(3):320–328
- Malleshi NG, Desikachar HSR (1986) Studies on comparative malting characteristics of some tropical cereals and millets. *J Inst Brew* 92(2):174–176
- McCleary BV, Codd R (1989) Measurement of β -amylase in cereal flours and commercial enzyme preparations. *J Cereal Sci* 9(1):17–33
- McCleary BV, Nurthen E (1986) Measurement of (1 $\rightarrow$ 3) (1 $\rightarrow$ 4)- β -d-glucan in malt, wort and beer. *J Inst Brew* 92(2):168–173
- McCleary BV, Sheehan HJ (1987) Measurement of cereal α -amylase: a new assay procedure. *J Cereal Sci* 6(3):237–251
- Palmer GH (ed) (1989) Cereals in malting and brewing. In: Cereal science and technology. Aberdeen University Press Ltd., Aberdeen, pp 61–242
- Qi JC, Zhang GP, Zhou MX (2006) Protein and hordein content in barley seeds as affected by nitrogen level and their relationship to beta-amylase activity. *J Cereal Sci* 43(1):102–107
- Rutger JN, Schaller CW, Dickson AD (1967) Variation and covariation in agronomic and malting quality characters in barley. II. Interrelationships of characters. *Crop Sci* 7(4):325–326

- Stuart IM, Loi L, Fincher GB (1988) Varietal and environmental variations in (1 → 3, 1 → 4)-β-glucan levels and (1 → 3, 1 → 4)-β-glucanase potential in barley: relationships to malting quality. *J Cereal Sci* 7(1):61–71
- Swanston JS (1980) The use of electrophoresis in testing for high diastatic power in barley. *J Inst Brew* 86(2):81–83
- Verma RPS, Sarkar B, Mishra B (2008) Improvement of two-row barley through two- x six-row hybridization in India. In: *Proceedings of the 10th international barley genetics symposium*. Alexandria, Egypt 5–10 April, pp 432–442
- Warle BM, Riar CS, Gaikwad SS, Mane VA (2015) Effect of germination on nutritional quality of barley. *Int J Food Nutr Sci* 4:59–63
- Yin C, Zhang GP, Wang JM, Chen JX (2002) Variation of beta-amylase activity in barley as affected by cultivar and environment and its relation to protein content and grain weight. *J Cereal Sci* 36(3):307–312
- Zhang N, Jones BL (1995) Development of proteolytic activities during barley malting and their localization in the green malt kernel. *J Cereal Sci* 22(2):147–155