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Evaluation of milling and nutritional quality of iron-biofortified lentil genotypes under different locations

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Abstract

Iron-biofortified lentils are only as useful as their end-use quality allows. This research evaluated milling recovery, iron and zinc retention, and protein of seven biofortified lentil genotypes at three locations in Emilia-Romagna, Italy (2022-2023). Genotype IBL-7 had the highest iron (74.1 mg/kg at Bologna) but lowest milling recovery (77.8%). A strong negative correlation ($r = -0.94$) existed between grain iron and milling recovery. IBL-4 offered the best balance: 49.8-55.3 mg Fe/kg with 83.1-85.1% recovery. Location effects were significant for iron but not protein. These findings highlight a trade-off between mineral density and milling quality that breeders should address.

Keywords: Iron biofortification, lentil genotypes, milling recovery, dehulling efficiency, nutritional quality, genotype-environment interaction, grain iron, pulse quality

Introduction

Breeding lentils for higher iron is pointless if the iron is lost during milling. Biofortification programmes have released dozens of iron-rich lentil lines, yet few trials have tested whether elevated mineral concentrations survive dehulling and splitting^[1, 2]. The seed coat, removed during dehulling, can hold 15-30% of total grain iron^[3]. Lentil is a key dietary protein and iron source for more than a billion people^[4]. Milling quality, the proportion of intact dehulled splits recovered directly affects market value^[5]. Location effects add complexity: soil type and temperature during grain filling alter seed coat thickness and mineral content^[6]. This research assessed milling recovery, iron and zinc retention, and protein of seven iron-biofortified lentil genotypes at three sites in northern Italy^[7].

Research area description

Trials were conducted at three sites in the Emilia-Romagna region: Bologna (44.49° N, 11.34° E, 54 m), Ravenna (44.42° N, 12.20° E, 4 m), and Ferrara (44.84° N, 11.62° E, 9 m). Bologna has a silty clay loam soil (pH 7.6), Ravenna a sandy loam (pH 7.9), and Ferrara a clay soil (pH 7.3). During the October 2022-June 2023 growing window, mean temperatures ranged from 6.8 to 22.4 °C and total rainfall was 412-538 mm across sites^[8].

Materials and Methods

Materials

Seven iron-biofortified lentil genotypes (IBL-1 through IBL-7) from the University of Bologna breeding programme were used. Seeds from the 2022-2023 harvest were cleaned and equilibrated to 11% moisture. A Satake TM-05 dehulling machine and Buhler MHXS dal mill were used for processing^[5].

Methods

A factorial RCBD (7 genotypes × 3 locations × 3 reps) was used. Plot size: 5 m × 1.5 m. Sowing: mid-October 2022; harvest: late June 2023. Milling recovery = (dehulled splits mass / initial mass) × 100. Iron and zinc by AAS after tri-acid digestion; protein by Kjeldahl (N × 6.25)^[9]. Iron retention = (mineral in dal / mineral in whole grain) × 100. Two-way ANOVA with Tukey's HSD at $p \leq 0.05$.

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Results

Table 1: Milling recovery (%) and grain iron concentration (mg/kg) of seven lentil genotypes across three locations

Genotype	MR Bol	MR Rav	MR Fer	Fe Bol	Fe Rav	Fe Fer	Mean Fe
IBL-1	82.4	83.7	83.1	58.2	52.6	55.9	55.6
IBL-2	80.1	81.4	80.8	63.7	59.1	61.4	61.4
IBL-3	78.6	79.9	79.3	71.4	66.8	69.1	69.1
IBL-4	84.3	85.1	84.7	49.8	45.3	47.6	47.6
IBL-5	83.1	84.2	83.6	55.3	50.7	53.1	53.0
IBL-6	79.2	80.6	79.9	67.9	62.4	65.2	65.2
IBL-7	77.8	78.4	78.1	74.1	69.3	71.8	71.7

MR = Milling recovery; Bol = Bologna; Rav = Ravenna; Fer = Ferrara

Genotype IBL-7 had the highest mean iron (71.7 mg/kg) but the lowest milling recovery (77.8-78.4%). IBL-4 showed the best milling performance (84.3-85.1%) at a moderate iron level

(45.3-49.8 mg/kg). Bologna consistently produced the highest grain iron across genotypes (Table 1).

Table 2: Nutritional quality parameters of lentil genotypes (mean across locations)

Genotype	Zn (mg/kg)	Protein %	Fe ret. %	Zn ret. %	Dehull %	NQI
IBL-1	38.4	24.7	76.3	81.2	91.4	64.8
IBL-2	41.7	25.1	74.8	79.6	89.7	68.3
IBL-3	44.9	24.3	72.1	77.3	87.2	71.6
IBL-4	35.1	25.8	79.4	84.1	93.6	61.2
IBL-5	37.6	25.3	77.6	82.4	92.1	63.7
IBL-6	43.2	24.6	73.4	78.1	88.4	69.9
IBL-7	46.3	23.9	70.8	75.9	85.8	73.4

Fe ret. = iron retention; Zn ret. = zinc retention; Dehull = dehulling efficiency; NQI = Nutritional Quality Index. Iron retention ranged from 70.8% (IBL-7) to 79.4% (IBL-4),

confirming high-iron genotypes lose more mineral during processing. Protein was stable (23.9-25.8%) with no genotype $\times$ location interaction.

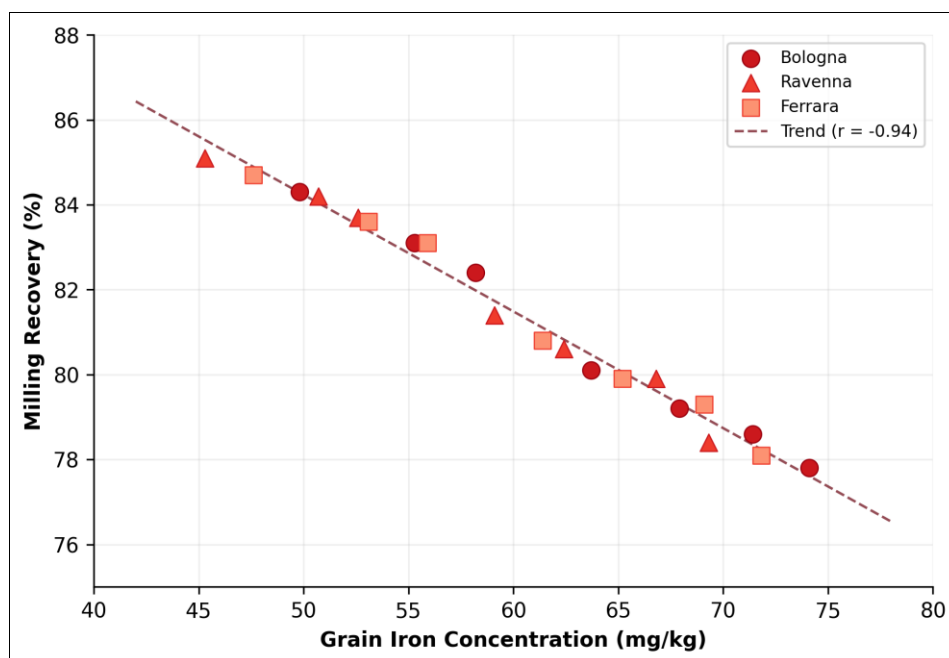


Fig 1: Grain iron concentration vs. milling recovery across genotypes and locations ($r = -0.94$).

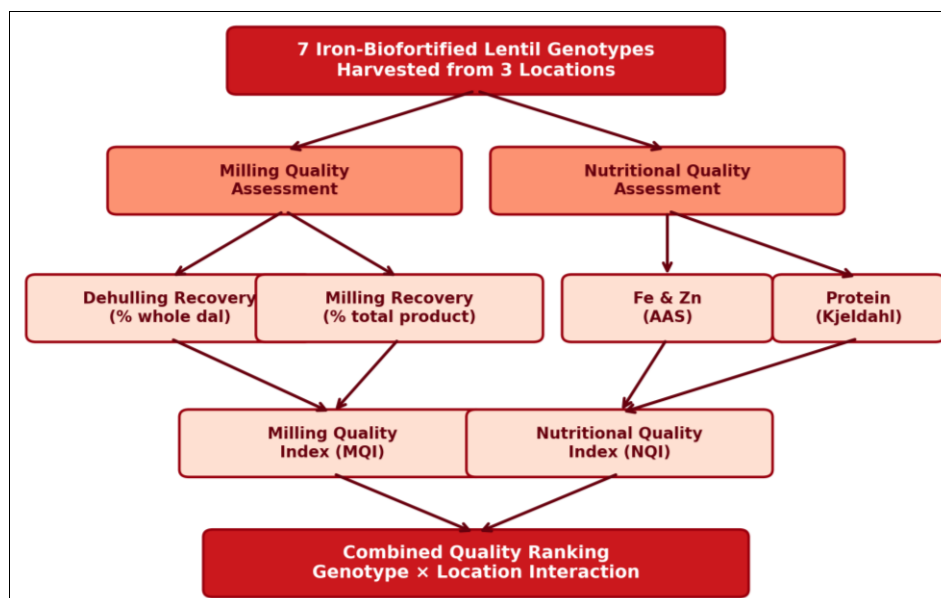


Fig 2: Schematic of the milling and nutritional quality evaluation workflow for biofortified lentil genotypes

Discussion

The strong negative correlation ($r = -0.94$) suggests high-iron genotypes have thinner or more brittle seed coats, causing greater breakage during dehulling [3, 10]. This trade-off has been observed in chickpea but wasn't previously documented for iron-biofortified lentils. IBL-4 is a practical compromise: its iron (mean 47.6 mg/kg) exceeds conventional lentils (28-35 mg/kg) [2] and its milling recovery above 84% meets commercial thresholds [5]. Bologna's higher iron values likely reflect heavier soil texture and higher organic matter improving iron availability during seed filling [6, 11]. Protein stability across sites is consistent with reports that lentil protein is under stronger genetic control than minerals [12]. Breeders should treat milling quality as a co-selection criterion alongside iron density [13, 14].

Conclusion

A clear trade-off exists between grain iron and milling recovery in iron-biofortified lentils ($r = -0.94$). IBL-7, richest in iron (71.7 mg/kg), had the poorest milling performance (< 79%). IBL-4 offered the best balance of moderate iron (47.6 mg/kg) and high milling recovery (> 84%), making it the most promising candidate for release. Location affected mineral content significantly, with Bologna producing the highest iron. Breeding programmes should incorporate milling recovery as a selection criterion to avoid releasing lines that lose market value during processing.

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