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Consumer preferred boiled cassava cooking qualities in white and yellow fleshed advanced breeding populations in Uganda

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ABSTRACT

Cassava root qualities that meet end-user preferences enhance adoption of varieties. In this study, softness and water absorption (WAB) which is a proxy for cooking time, were assessed in white and yellow fleshed breeding lines, to identify superior lines for recycling as progenitors or advancement in the variety development pipeline. Softness of boiled roots was measured with a penetrometer and WAB using a gravimetric assay. Using a weighted selection index, genotypes UG15F233P046, NAROCASS1 (commercial check), UG15F190P001, UG15F079P002 all white fleshed and UG15F177P502 (yellow fleshed) were ranked overall best in terms of combining softness, dry matter, root number and fresh root yield. Genotypes UG15F173P007 (softest) and UG15F007P013 (highest WAB) could be recycled as progenitors for superior cooking qualities. Also, we did not find significant differences ($p<0.05$) between white and yellow fleshed cassava for softness and water absorption (WAB) across the two locations. Broad sense heritability (H2) was low for both softness (0.27) and WAB (0) possibly due to narrowing of genetic diversity from previous selection cycles. Also, the significant negative correlation between softness and WAB30 (-0.66) may be exploited to simultaneously select for both traits, since softness has higher heritability than WAB. These findings point out the importance of including consumer preferences in selection indices during variety development, as a possible strategy to increase adoption rates of improved varieties.

Key words: Cassava, cooking qualities, end-user selection, Uganda

RÉSUMÉ

Les qualités racinaires du manioc qui répondent aux préférences des utilisateurs finaux favorisent l'adoption de variétés. Dans cette étude, la douceur et l'absorption d'eau (WAB), qui est un proxy du temps de cuisson, ont été évaluées dans des lignées de sélection à chair blanche et jaune, pour identifier les lignées supérieures à recycler comme géniteurs ou à faire progresser dans le pipeline de développement des variétés. La douceur des racines bouillies a été mesurée avec un pénétromètre et WAB à l'aide d'un essai gravimétrique. En utilisant un indice de sélection pondéré, les génotypes UG15F233P046, NAROCASS1 (témoin commercial), UG15F190P001,

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UG15F079P002 tous à chair blanche et UG15F177P502 (à chair jaune) ont été classés comme les meilleurs en termes de combinaison de douceur, de matière sèche, de nombre de racines et de rendement en racines fraîches. Les génotypes UG15F173P007 (le plus doux) et UG15F007P013 (WAB le plus élevé) pourraient être recyclés comme géniteurs pour des qualités de cuisson supérieures. De plus, nous n'avons pas trouvé de différences significatives ($p < 0{,}05$) entre le manioc à chair blanche et jaune pour la douceur et l'absorption d'eau (WAB) sur les deux sites. L'héritabilité au sens large (H2) était faible pour la douceur (0,27) et WAB (0), probablement en raison du rétrécissement de la diversité génétique des cycles de sélection précédents. De plus, la corrélation négative significative entre la douceur et WAB30 (-0,66) peut être exploitée pour sélectionner simultanément les deux traits, la douceur ayant une héritabilité plus élevée que WAB. Ces résultats soulignent l'importance d'inclure les préférences des consommateurs dans les indices de sélection lors du développement de variétés, comme une stratégie possible pour augmenter les taux d'adoption de variétés améliorées.

Mots-clés : Manioc, qualités de cuisson, sélection par l'utilisateur final, Ouganda

INTRODUCTION

In Sub-Saharan Africa, cassava (*Manihot esculenta*) is one of the major sources of calories providing sustenance to over 700 million consumers on the continent (Szyniszewska, 2022). In Uganda, the Northern and Eastern regions account for most of the production and about 50% of all cassava produced in the country is consumed fresh and the rest processed into various forms including flour (Nakabonge *et al.,* 2018). The fresh cassava roots are predominantly consumed after boiling, though steaming and frying are also popular methods of preparation (Waigumba *et al.,* 2016). Cultivation of the crop is still predominantly subsistence, with farmers growing a blend of both improved cultivars and landraces; preference for cultivation is largely determined by a variety's fit-to-purpose for food and or industrial use (Esuma *et al.,* 2019). Therefore, breeders need to deliberately incorporate some of the key identified end-user preferred traits such as softness of boiled roots, cooking time, starch, among others, in their selection indices at critical breeding stages to increase variety adoption and thus genetic gain in farmers' fields (Forsythe *et al.,* 2020; Thiele *et al.,* 2020).

For boiled cassava, softness of the cooked root is one of the prime textural attributes linked to consumer acceptance (Iragaba *et al.,* 2019) or even industrial application (Maieves *et al.,* 2012). Similarly, water absorption of roots during cooking has also been confirmed as a predictor of cooking time, another important consumer preferred trait (Tran *et al.,* 2020). In Uganda, the National cassava breeding program has initiated breeding processes that aim at integrating end-user trait preference in variety selection. This strategy is being adopted for both white fleshed and provitamin A cassava varieties. However, these cooking qualities have not been previously represented in selection indices, resulting in low gains and low usability of improved varieties.

Therefore, the aim of this study was to; i) evaluate white and yellow fleshed advanced cassava populations for coking qualities in boiled cassava to inform selection, and ii) evaluate the relationship between cooking qualities of boiled cassava and other root and other root attributes.

METHODS

Study sites. The experiments were established at two locations representing two distinct agroecological zones (Namulonge in central and Tororo in Eastern Uganda). A panel of 36 genotypes of varying genetic backgrounds were selected for this study, of which 25 were white and 11 yellow fleshed. At each location, the trials were laid out in alpha lattice incomplete block design with two replications. Each plot area measured 7 × 7 m with a total of 64 plants and inter-plant distance was 1 × 1 m. At harvest, cooking quality and agronomic data were collected from six randomly selected roots from each plot. Waster absorption (WAB) was determined according to the procedures by Tran *et al.* (2020) and softness according to Iragaba *et al*. (2019) with minor adjustments using a penetrometer (Model number: FHT-1122, Vetus Industrial Company Limited, Hefei, China). Root dry matter content (DMC) was accessed according to Kawano *et al.* (1987), and root number and fresh root yield (FRY) using standard methods.

Data analysis. This was done using restricted maximum likelihood technique (de Oliveira *et al.,* 2015) and variance components for the measured traits were estimated after fitting a mixed effects model using the lmer function of the lme4 package in R (R core team 2019). The genotype, block nested within the replication and genotype by location were all considered random effects, while location was fixed. Variance components from this model were used to estimate broad sense heritability for the assessed traits in either white or yellow fleshed clones or across both. BLUPS were also extracted from the mixed model and used in a weighted selection index to rank best genotypes overall. Phenotypic correlations among the traits were calculated using Spearman correlation coefficient at 5% significance level using the cor function in R statistical software.

RESULTS AND DISCUSSION

The urgent need to prioritize consumer demanded traits during selection cycles of cassava (Forsythe *et al.,* 2020) has resulted in a frenzy of efforts targeting improved phenotyping of these traits, understanding their genetic architecture (Thiele *et al.,* 2020) and identifying unique lines for hybridizations in order to increase genetic gains. This is all geared towards increasing functionality of improved cassava varieties for food and industrial use. In this study, we focused on softness and water absorption (WAB) which have been found to play a critical role in variety adoption (Tran *et al.,* 2020; Iragaba *et al.,* 2021). Softness refers to the maximum force required to penetrate cooked cassava (Iragaba *et al.,* 2019) and is an important trait for Ugandan communities where consumption of boiled cassava is common.

Variation across white and yellow fleshed genotypes. Across white and yellow fleshed genotypes, there was no genetic variation for water absorption (WAB) at 30 and 45 minutes of boiling (Table 1). Conversely, there was low genetic variance for softness (6.25%) and relatively high genetic variance (21.63%) for dry matter content (DMC). A bigger portion of the variance for cooking qualities (softness, WAB) was attributed to the genotype by location interaction (GxL) but the largest source of this variation was attributed to residual effects (Table 1). However, the low genetic diversity among both yellow and white fleshed genotypes used in this study may have masked potential differences among these two types of cassava. Elsewhere, (Nuwamanya *et al.,* 2010; Noor *et al.,* 2013) found yellow fleshed genotypes to be softer than wight fleshed ones in a participatory variety selection (PVS) experiment.

Segregation of yellow and white fleshed genotypes. All genotypes segregated based on location rather than type (white or yellow) for all cooking qualities (Figure 1). For DMC, both white and yellow fleshed genotypes performed relatively similarly across locations (Figure 1C). For softness, genotypes segregated into three sub-groups (Figure 1A); very soft (< 1 kgfcm^{-2}), soft (1 – 2.5 kgfcm^{-2}) and moderately soft (>2.5 kgfcm^{-2}). For WAB30 and WAB45, genotypes segregated in two sub-groups (Figure 1B&C); low-water absorbers (< 15%) and high-water absorbers (> 15%). At WAB45, more genotypes absorbed water beyond 15% compared to WAB30.

Table 1. Percent of total variance contributed by different sources in white and yellow genotypes

Source	Type	N	Soft45	WAB30	WAB45	DMC
Genotype (G)	Whit – Yel	36	6.25	0.00	0.00	21.63
Rep (Block)	Whit – Yel	36	18.75	16.95	13.12	0.00
Type	Whit – Yel	36	0.00	0.00	3.96	14.61
G x L	Whit – Yel	36	8.75	46.53	32.36	16.89
Residual	Whit – Yel	36	66.25	36.51	50.56	46.87
H^2	Whit – Yel	36	0.27	0.00	0.00	0.52

GxL - Genotype by Location interaction; Whit-PVAC - Combined white and yellow (provitamin A clones) fleshed genotypes; soft45 - Softness measured after 45 minutes of boiling; WAB30 & WAB45 - water absorption measured after 30 and 45 minutes of boiling; DMC - dry matter content.

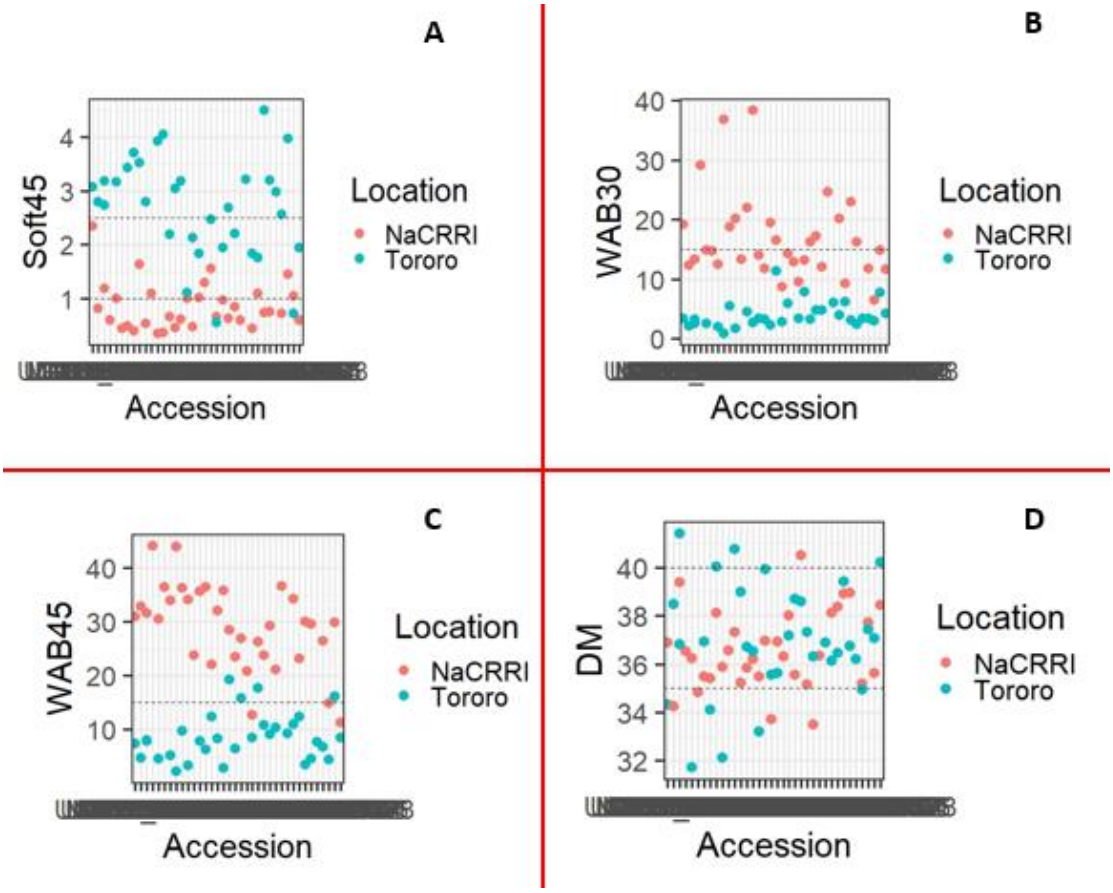

Figure 1. Scatter plots showing variability of combined yellow and white fleshed genotypes with respect to environment. Soft45 - Softness measured after 45 minutes of boiling; WAB30 & WAB45 - water absorption measured after 30 and 45 minutes of boiling; DMC - dry matter content

Trait heritabilities. Broad sense heritability (H^2) estimates for cooking qualities across type and location ranged from very low in WAB30 and WAB45 to moderate for DMC (0.52). Softness had H^2 of 0.27 in both yellow and white genotypes across locations. The low heritabilities are largely due to stronger influence of genotype by location (GxL) effects on expression of cooking traits (Table 2). Conversely, Iragaba *et al*. (2019) found a maximum H^2 of 0.37 for softness on boiled cassava when 285 genotypes were evaluated in two locations. This implies that heritability for softness could improve further with increasing genetic diversity. This notion is corroborated by another study where heritability estimates of yield in maize decreased from C0 to C1 owing to reduction in genetic diversity associated with selection and population stabilization (Szyniszewska, 2020.). For single locations, heritability estimates for WAB were generally higher at 30 than 45 minutes of boiling, which indicates that the former is a more suitable cooking time for evaluating WAB differences among genotypes. At 45 minutes of boiling, distinctions among genotypes for WAB may not be very clear, resulting in low phenotypic and genetic variance.

Summary of traits evaluated in different environments. Both white and yellow fleshed genotypes evaluated at Namulonge were generally softer than in Tororo (Table 3). Average softness ranged from 0.86 (NaCRRI, white) to 2.73 kgfcm^{-2} (PVAC, Tororo). Likewise, all genotypes evaluated at Namulonge had higher WAB30 and WAB45 compared to Tororo. Average WAB30 ranged from 3.27 (PVAC, Tororo) to 17.35 (PVAC, NaCRRI), while WAB45 ranged from 7.75 (PVAC, Tororo) to 30.53 (white, NaCRRI). Generally, WAB45 was higher than WAB30 for most genotypes across different locations. Exceptions included UG15F106P002 and UGC14191 (PVAC, NaCRRI) which had higher WAB30 than WAB45. Average DMC ranged from 36.25 (NaCRRI, white) to 37.88 (Tororo, PVAC).

The relatively high DMC across white and yellow fleshed genotypes (Figure 2) could be reflective of gains and stability made for DMC since the trait was selected for right from the clonal evaluation stage. Therefore, dry matter had minimal GxL effect, implying that the evaluated genotypes were relatively stable for dry matter in the selected environments.

Ranking of white and yellow fleshed genotypes using a weighted selection index. Genotype UG15F233P046 (white) was the overall best combining cooking and agronomic traits followed by UG110017 (NAROCASS 1) a popular commercial check. Genotype UG15F177P502 was the only yellow fleshed clone among the top five. On the other hand, UG15F177P016 (yellow flesh) was the worst ranked across all traits, but in stark contrast, the same clone was the softest after boiling. Interestingly, UG15F007P013 had the highest WAB much as it ranked 27th overall.

Overall top ranked clones are candidates for advancement in the variety development pipeline to national performance trials (NPT). Genotypes superior for only softness or WAB could be recycled in the breeding pipeline as progenitors.

Correlation analysis of traits. Softness was significantly negatively correlated with WAB30 (-0.66, p 0.001) and WAB45 (-0.77, p 0.001), but correlation with dry matter was very low and insignificant (Table 3). Generally, soft genotypes had high water absorption (Figure 2). However, WAB30 was significantly positively correlated with WAB45 (0.88, p 0.001); there was no relationship between water absorption and DMC.

Table 2. Selection index ranking of white and yellow fleshed genotypes in each environment

Rank	Accession	SOFT	WAB	DMC	Root_no	FRY	SI
1	UG15F233P046	-1.57	4.03	0.47	83.51	19.90	109.48
2	UG110017	0.48	-3.57	3.16	74.53	34.93	108.56
3	UG15F190P001	-0.58	1.20	-1.06	94.49	9.61	104.82
4	UG15F079P002	0.41	2.71	-2.76	77.36	26.08	102.98
5	UG15F177P502	-0.76	-3.87	2.98	53.09	31.28	84.24
6	UGC14191	-0.27	-3.68	2.53	47.29	29.04	75.45
7	UG15F034P001	-1.09	-0.65	-0.87	43.97	20.06	63.59
8	UG15F302P016	0.15	0.00	0.78	35.88	16.98	53.49
9	UG15F158P001	0.05	3.33	-1.13	33.89	8.54	44.57
10	UG15F170P507	0.03	2.56	-2.27	17.59	21.23	39.08
11	UGC14079	0.18	-3.40	-1.50	41.48	-2.33	34.06
12	MKUMBA	2.59	-0.04	-1.11	36.41	-4.09	28.59
13	UG15F177P005	0.57	-3.44	0.64	22.84	-1.53	17.94
14	UG15F201P517	1.06	0.71	0.04	18.82	-3.39	15.12
15	UG15F064P087	2.08	3.02	2.51	13.84	-2.35	14.93
16	UGC14142	-1.29	-4.23	-0.32	-1.96	2.73	-2.50
17	UG15F017P003	0.21	1.01	-2.78	-0.01	-2.15	-4.13
18	UG15F079P011	-1.44	2.47	-0.89	0.26	-9.98	-6.70
19	UG15F272P004	0.17	-3.57	1.78	1.16	-8.26	-9.06
20	UG15F140P003	0.40	-0.91	-0.30	-5.50	-3.27	-10.38
21	UGC14083	2.56	-3.13	0.93	-15.73	5.40	-15.09
22	UG15F306P028	0.89	-0.29	-0.69	-9.77	-3.92	-15.57
23	UG15F106P002	0.17	-3.14	1.23	-7.41	-6.77	-16.26
24	UG15F020P001	-0.59	3.14	-1.29	-29.37	4.48	-22.45
25	UG15F173P007	-1.58	3.46	0.07	-28.10	-1.50	-24.50
26	UG15F192P017	-0.17	0.39	-1.83	-33.98	0.77	-34.48
27	UG15F007P013	0.24	5.85	0.68	-36.61	-4.69	-35.01
28	UG15F079P014	-0.13	2.57	1.16	-26.73	-14.51	-37.39
29	UG15F162P003	-0.97	3.74	1.31	-28.32	-15.25	-37.55
30	UG15F055P009	-0.31	-3.34	-1.06	-27.87	-20.10	-52.06
31	UG15F113P001	-0.55	-3.69	-0.41	-54.31	-11.60	-69.46
32	MM14_0629	0.48	-3.60	0.06	-57.89	-13.71	-75.62
33	UG15F258P002	0.18	-1.17	0.64	-64.48	-16.05	-81.24
34	UG15F196P004	-0.09	4.13	-0.22	-61.45	-24.97	-82.42
35	UG15F176P502	0.71	-0.99	-0.30	-91.20	-24.13	-117.32
36	UG15F177P016	-2.23	2.41	-0.18	-115.69	-36.47	-147.70

Table 3. Summary of performance of genotypes in different locations

Location	Type	Measure	Soft45	WAB30	WAB45	DMC
Nam	White	Mean	0.86	16.64	30.53	36.25
	White	Min - Max	0.35 – 2.35	8.67 – 29.11	20.76 – 43.99	30.95 – 39.94
	White	H2	0.35	0	0	0
	White	CV	56.34	30.39	19.56	4.58
	PVAC	Mean	0.88	17.35	26.23	37.04
	PVAC	Min - Max	0.37 – 1.56	6.48 – 38.41	11.28 – 43.79	34.25 – 40.49
	PVAC	H2	0.26	0.95	0.98	0.92
	PVAC	CV	43.53	59.20	37.57	5.45
Tororo	White	Mean	2.64	4.07	9.03	36.41
	White	Min - Max	0.56 – 3.93	0.56 – 11.26	2.88 – 19.24	31.72 – 40.77
	White	H2	0	0	0.39	0.77
	White	CV	32.77	54.56	49.58	6.54
	PVAC	Mean	2.73	3.27	7.75	37.88
	PVAC	Range	0.73 – 4.06	0.78 – 7.67	2.18 – 16.12	33.84 – 42.54
	PVAC	H2	0.44	0.82	0.53	0.71
	PVAC	CV	36.06	49.78	49.85	5.75
Nam-Tor	White	Mean	1.67	11.19	20.96	36.33
	White	Min - Max	0.44 – 3.22	3.24 – 29.11	7.72 – 43.99	33.99 – 39.08
	White	CV	47.50	51.24	40.17	3.75
Nam-Tor	PVAC	Mean	1.83	10.62	16.67	37.51
	PVAC	Min – Max	0.69 – 2.83	3.39 – 29.62	8.75 – 30.04	34.98 – 40.39
	PVAC	CV	34.03	66.37	37.36	4.71
Nam-Tor	Both	Mean	1.70	10.99	19.86	36.68
Nam-Tor	Both	Min – Max	0.44 – 3.22	3.29 – 29.11	7.72 – 43.99	33.99 – 39.68
Nam-Tor	Both	CV	40.86	50.76	39.03	4.25

Nam – Namulonge; Nam-Tor – Namulonge & Tororo; PVAC – provitamin A clone (yellow fleshed); soft45 - Softness measured after 45 minutes of boiling; WAB30 & WAB45 - water absorption measured after 30 and 45 minutes of boiling; DMC - dry matter content

Table 4. Phenotypic correlations among traits

	Soft45	WAB30	WAB45	DM
Soft45	1	-0.66***	-0.77***	0.01
WAB30		1	0.88***	-0.04
WAB45			1	0.01
DM				1

soft45 - Softness measured after 45 minutes of boiling; WAB30 & WAB45 - water absorption measured after 30 and 45 minutes of boiling; DMC - dry matter content

A strong negative correlation between softness and WAB30 and WAB45 implies that cassava roots tend to get softer as they absorb more water during cooking. In this study, genotypes that had less than 15% water absorption were generally harder in texture and vice versa (Figure 2), 16 confirmed this relationship when mealy and soft cassava was found to absorb significantly more water (> 15%) than the hard genotypes. Also, fast cooking genotypes have minimal implications on energy expenditure during cooking, which is desirable for end-users (Miranda *et al.,* 2020).

Water absorption during cooking of cassava has been attributed to uptake of water by starch granules under the influence of temperature (Nuwamanya *et al.,* 2010). These conditions cause starch granules to swell and distend the cell wall and eventually burst. But starch granule composition viz a viz amylose/amylopectin ratios and their respective molecular weights could also influence how much water is absorbed (Mufumbo *et al.,* 2011).

However, phenotyping cooking traits remains a big challenge considering the laborious and costly processes involved. Emphasis should therefore be placed on development of high throughput phenotyping strategies geared at either one or both traits. Further, there is need to explore more associations between other root physicochemical properties and cooking qualities in order to find surrogates that could be used to predict softness and cooking time.

CONCLUSION

This study provides preliminary findings on boiled cassava cooking qualities in both white fleshed and provitamin A cassava clones. There were no differences in softness and cooking time between yellow and white fleshed clones. The study identified both white and yellow fleshed genotypes with superior all round performance for cooking and agronomic qualities. These will be advanced in the variety development process. The low heritability observed for water absorption and softness across locations were a result of stronger influence of the genotype by environment interaction effects on expression of these traits. The magnitude of the genotype by environment interaction (GEI) on heritability of cooking qualities should be investigated further by testing diverse a set of genotypes in several agroecological zones. This would inform selection strategies for these traits in future breeding efforts to maximize resources and gains. Overall, this study is expected guide future efforts for breeding for cooking qualities in yellow and white fleshed varieties in Uganda.

Data availability statement

The datasets presented in this study are available online at www.cassavabase.org.

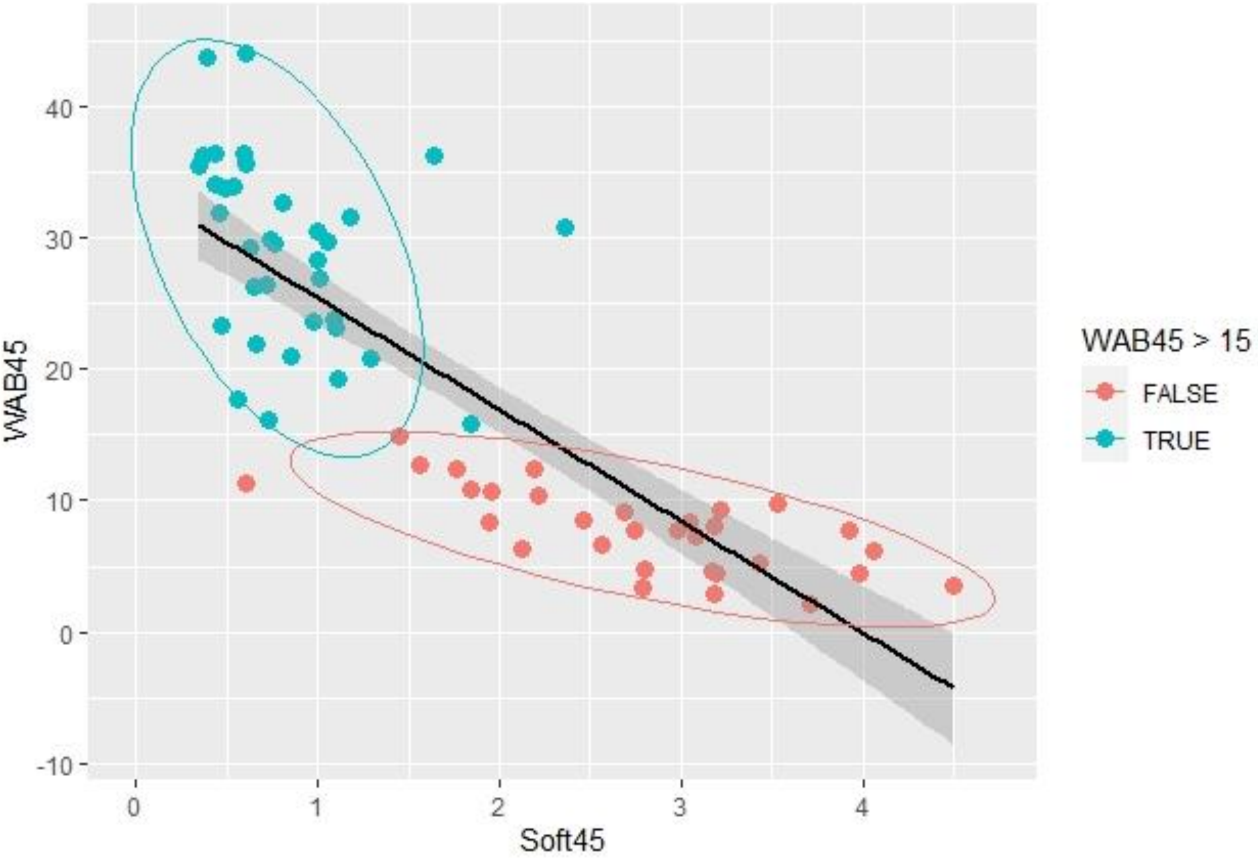

Figure 2. Scatter plot highlighting relationship between softness (Soft45) and water absorption after 45 minutes of boiling (WAB45)

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STATMENT OF NO CONFLICT OF INTEREST

The author declare that there is co conflict of interest in this paper.

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