A CONTRIBUTION TO THE STUDY OF FACTORS AFFECTING THE QUALITY AND COMPOSITION OF POTATOES.

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THE work was undertaken with the hope of establishing some connexion between the characters of soils as shown by chemical and mechanical analyses, and the quality and composition of the potatoes grown on them. As regards quality, most attention has been given to the occurrence of 'blackening' after cooking, especially after a second warming up, and an attempt has been made to get at the cause of this phenomenon. This defect has been often complained of by potato growers and dealers, and seriously affects the price of samples marketed for consumption in towns where the largest buyers are hotels and restaurants which demand a potato capable of keeping its colour after a second steaming. 'Blackening' is often associated with sandy soils heavily manured with farmyard dung or town manure, and it has been observed in tubers grown with spring dressings of kainite; concordant opinions, however, are not to be had from practical men, and in fact the defect may arise on the most widely different types of soil. In order to exclude disturbances due to variety, 'Up to Date,' as one of the most widely grown sorts, has alone been investigated.

SOILS AND POTATO SAMPLES OF THE SEASON 1903.

During the summer of 1903 samples were taken of soil and subsoil from two soils in the neighbourhood of Dunbar, one, at North Belton, from a field which produces potatoes showing a tendency to blacken, and the other at Thornton Loch, from land that can be depended on for a good quality crop. Soil and subsoil were each sampled to a depth of 9 inches. In the autumn samples of potatoes from these soils were kindly forwarded by Mr J. D. Bowe, Dunbar, by whom the soils in question had been pointed out. Both soils are of 'drift' origin but preserve the character of the underlying Old Red Sandstone rock.

During the autumn a visit was made to Boston, Lincs., and samples of soil and subsoil were taken from two fields on the farms of Mr J. H. Dennis, to whom I am indebted for help and information. Samples of potatoes just raised from these soils were also secured. The soil designated 'warp A' had only recently been reclaimed, and was carrying its first crop of potatoes. It is separated from the sea by a marsh several miles wide. The 'warp B' soil lies two miles further inland and has been under cultivation for a much longer time. Both soils are of natural formation, and have not been produced by artificially regulated deposit like those of the Humber district. Oats preceded the potato crop on both soils, and the latter received a dressing of about 12 tons of farmyard manure, and an artificial mixture containing 5—6 p.c. ammonia, 20—25 p.c. phosphates, and 5—6 p.c. potash at the rate of 6 cwt. to the acre. Two samples of potatoes were obtained from 'warp A' field, one from a portion where the growth had been normal, and the other from a part where the haulm had died off prematurely owing to disease.

A sample of potatoes was obtained from the Royal Agricultural Society's experimental farm at Woburn, grown on soil of which a mechanical analysis had been made at the Rothamsted Laboratory.

Cooking Test.

The potatoes peeled and unpeeled were steamed under atmospheric pressure for one hour, allowed to get quite cold and again steamed for half-an-hour, and after cooling broken into halves either across or lengthwise. Some were cooked by boiling in water, and after cooling were given a steaming for half-an-hour. The results are arranged in the order of quality.

1. Thornton Loch. Good colour. No 'blackening' at heel end.
2. Woburn. „ Slight „ „ „
3. Warp B. Stronger. Darkening at heel end.
4. North Belton. Blackened at heel end.
5. Warp A (mature) } Very white and waxy and much
6. „ A (immature) } blackened in cortex and at heel end.

In no case was the 'blackening' very marked, and with the exception of the samples from 'warp A' was confined to the heel third of the tuber, being most evident near the scar marking the place of attachment to the rhizome. In the case of the 'warp A' samples the blue-black discolouration extended up the cortex towards the seed end. The appearance was least marked in the potatoes which were boiled, and those cooked in the skins were always more 'blackened' than the peeled tubers with similar treatment.

MECHANICAL ANALYSES OF SOILS.

The method employed was that described by Hall[1], and the calcium carbonate determinations were made with the apparatus devised by Hall and Russell[2]. The results are set out in Table I., the stones and calcium carbonate being calculated on the air-dry material.

It is evident that all the soils fall within the categories of 'sand' and 'sandy loam' in virtue of the high proportion of grit and sand particles, and the low amounts of 'Klay.' The Thornton Loch soil and subsoil show a very even distribution of all grades, the fractions ensuring porosity being well balanced by an adequate supply of the finer particles which give retentiveness.

The North Belton soil, on the other hand, is rather short of the finest fractions. The 'warp A' soil shows a very unusual composition with its very high percentage of 'sand,' absence of grit and stones, and extremely low amounts of fine silt and 'Klay.' The 'warp B' soil is better balanced with a higher 'Klay' content, but is also lacking in 'grit' and stones to counteract a tendency to 'run' and set. The best potatoes (see 'cooking test') are from the light soils with the most 'Klay,' Thornton Loch with its model composition standing first, and the bad cookers from the soils deficient in the finest particles.

CHEMICAL ANALYSES OF SOILS.

These are given in Table II. The citric acid soluble potash and phosphoric acid were determined by Dyer's method[3]. 'Soluble humus' was determined in 5 grams of soil rubbed up with dilute acid and allowed to stand 1 hour, thrown on a large Buchner filter, washed free from acid and treated with ammonia, using the filter pump (1 part strong ammonia and 1 part water) till the filtrate came away colourless. The dark liquid was evaporated and dried at 100° C. and weighed, and after ignition again weighed, the difference being set down as 'soluble humus.'

[1] A. D. Hall, *The Soil*, 1901, p. 48. *Trans. Chem. Soc.*, 1904, Vol. LXXXV. p. 950.
[2] *Trans. Chem. Soc.*, Vol. LXXXI. p. 81, 1902.
[3] B. Dyer, *Journ. Chem. Soc.*, 1894, Vol. LXV. p. 115.

Table I. Mechanical analyses of soils.

	Stackyard Field, Woburn		North Belton, Dunbar		Thornton Loch, Dunbar		'Warp A,' Boston		'Warp B,' Boston	
	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil
Stones, over 3 mm. (determined on entire sample)	0·00	0·00	11·37	12·66	9·65	5·41	0·11	0·00	0·00	0·00
Moisture dissolved by acid ...	1·83	2·26	4·30	3·27	3·14	3·00	4·40	5·56	3·23	3·52
Loss on ignition	3·84	2·70	6·92	5·70	6·16	4·78	6·95	6·16	6·35	5·35
Calcium carbonate	—	—	0·15	under 0·10	0·31	0·19	0·90	3·78	under 0·10	under 0·10
Fine gravel, 3—1 mm.	1·01	1·02	3·00	4·14	0·99	0·88	0·00	0·00	0·00	0·00
Grit, 1—·2 mm.	49·91	50·12	33·80	36·79	23·66	21·70	0·23	0·19	0·11	0·10
1st sediment, ·2—·04	16·11	15·85	28·00	26·07	38·18	35·60	65·72	66·13	53·58	53·04
2nd ,, ·04—·01	11·05	12·52	5·55	5·44	6·81	8·75	9·89	8·82	12·32	11·00
3rd ,, ·01—·004	3·50	3·89	8·40	4·58	5·86	7·08	8·40	5·85	7·89	7·83
4th ,, ·004—·002	2·06	2·05	2·40	3·84	5·94	3·56	1·91	3·57	2·43	2·70
'Klay,' ·002 and less	9·68	8·56	6·56	9·52	9·48	14·82	2·64	3·70	14·66	16·58
Total (excluding stones and calcium carbonate)	98·99	98·97	98·93	99·35	100·22	100·17	100·14	99·98	100·57	100·12

Table II. Chemical analyses of soils.

	North Belton, Dunbar		Thornton Loch, Dunbar		'Warp A,' Boston		'Warp B,' Boston	
	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil	Soil	Subsoil
Water	1·72	2·23	1·08	2·06	1·85	1·72	2·06	2·23
Loss on ignition	6·92	5·70	6·16	4·78	6·95	6·16	6·35	5·35
Nitrogen	·171	·139	·162	·087	·223	·116	·184	·134
Potash, K_2O	·286	·329	·460	·527	·532	·494	·629	·645
Citric sol. K_2O	·01	—	·023	—	·04	—	·017	—
Phosphoric Acid, P_2O_5 ...	·16	·129	·120	·042	·125	·103	·189	·136
Citric sol. P_2O_5	·034	—	·022	—	·024	—	·034	—
Calcium carbonate, $CaCO_3$	·150	under ·10	·314	·187	·902	3·780	·08	under ·10
Lime, CaO	·88	·71	·90	·70	1·175	2·50	·62	
Magnesia, MgO	·66	·63	·65	·69	·74			
Ferric oxide, Fe_2O_3	4·74	4·18	5·50	3·40	3·10	3·10	3·60	4·15
Manganese oxide, Mn_2O_3...	·21	·13	·15	·14	·10	?	·14	·15
Insoluble residue	84·35	84·22	85·18	85·40	85·11	82·88	83·91	83·00
Soluble humus	·90	·70	·62	·52	·88	·32	·80	·58

All the soils show high nitrogen figures, and so also do the warp subsoils. The total potash is correlated with the amount of 'Klay,' and is very low in the North Belton soil. The 'citric acid soluble' potash is very low in North Belton and 'warp B' soils, and is probably below the limit of safety for a crop like potatoes. Phosphoric acid is lacking in none of the soils, and the citric acid figures indicate high availability throughout. Calcium carbonate is very deficient in both the North Belton and the 'warp B' soils. Ferric oxide, a high proportion of which is often said to accompany good quality potatoes, is about the same in all the soils.

The Thornton Loch soil shows no chemical weakness, but its neighbour North Belton is very short of available potash and calcium carbonate, defects which could very well account for the inferior quality of potatoes raised from it. On the other hand, the 'warp A' soil, yielding the worst potatoes, gives a very good chemical analysis.

ANALYSIS OF TUBERS.

The 'specific gravity' was determined on about 1000 grams of medium sized tubers by weighing in air and again in distilled water. Dry matter and starch were determined in the air-dry meal after rapid drying of the sliced material at 55° C. Starch was estimated by a method described[1], depending on the action of a malt extract of predetermined 'diastatic activity' upon starch paste for a fixed time at constant temperature. The malt, kindly sent from the Guinness Laboratory had a 'conversion factor' of 82, *i.e.* by acting for 1 hour at 57° C. on a starch paste, 82 parts of maltose were formed for every 100 original parts of starch. The 'cupric reduction' of the resulting product was determined directly and calculated for maltose.

The results are given in Table III.

TABLE III.

Origin of potatoes	Specific gravity	Dry matter per cent.	Starch per cent.	
			in dry matter	in fresh substance
North Belton	1·0944	23·31	81·6	19·02
Thornton Loch	1·0899	21·85	78·0	17·04
Woburn	1·0858	20·99	79·1	16·60
Warp A, immature	1·0750	18·93	68·0	12·87
Warp A, mature	1·0810	20·15	70·17	14·14
Warp B	1·0870	21·30	74·8	15·93

[1] *Trans. Guinness Laboratory*, Vol. I. No. 1.

The specific gravity, and dry matter, do not appear to show much relation to quality, although the three best lots stand near together. The low proportion of starch in the dry matter of potatoes from both 'warp' soils is worthy of note.

The nitrogen determinations were made on the fresh unsprouted material. A dozen average sized tubers were rasped down as fine as possible, well mixed, and portions withdrawn at once for the various estimations. The figures for the proteid nitrogen were obtained by adding the 'insoluble' nitrogen to that contained in the precipitate formed by boiling the filtrate for three minutes with a few drops of 5 per cent. acetic acid. The results are shown in Table IV. It will be observed that, on the whole, a low proportion of total nitrogen and a high proportion of non-proteid nitrogen accompany good quality. This is well shown by comparing the figures for the good quality potatoes from Thornton Loch and Woburn, with those for the two bad samples from 'warp A.'

TABLE IV.

Nitrogen determined in fresh tubers.

	North Belton	Thornton Loch	Warp A, immature	Warp A, mature	Warp B	Woburn
(*a*) Per cent. in dry matter						
Total	1·04	1·28	1·42	1·55	1·44	1·25
Insoluble	0·23	0·24	0·22	0·33	0·27	0·18
Precipitated by acetic acid	0·25	0·26	0·52	0·62	0·33	0·33
Proteid	0·48	0·50	0·74	0·95	0·60	0·51
Non-proteid	0·56	0·78	0·68	0·60	0·84	0·74
(*b*) Per cent. in fresh substance						
Total	·237	·270	·270	·315	·301	·261
Proteid	·109	·107	·140	·191	·125	·104
Non-proteid	·128	·163	·130	·124	·176	·157
(*c*) Distribution of Nitrogen in parts per hundred of total Nitrogen						
Insoluble	21·94	18·88	15·19	21·58	18·27	14·18
Acetic acid precipitate	24·05	20·74	36·66	39·68	23·22	25·67
Proteid	45·99	39·62	51·85	61·26	41·49	39·85
Non-proteid	54·01	60·38	48·15	38·74	58·51	60·15

The results for the ash analyses are given in Table V.

The low amount of potash in the North Belton ash corresponds to a deficiency in the soil.

The high chlorine figures for the ash of the three bad samples stands in harmony with the often observed bad quality of potatoes manured with large dressings of chloride of potash or kainite.

TABLE V.

Ash of potatoes.

Pure ash—parts per hundred of dry matter.

Constituents—parts per hundred of pure ash.

Origin	Pure ash	Potash	Phosphoric acid	Lime	Magnesia	Chlorine	Ferric oxide
North Belton	3·28	53·84	11·60	1·28	3·25	6·42	·43
Thornton Loch ...	3·97	56·32	9·70	1·04	3·52	2·57	·25
Warp A, immature	5·36	56·35	10·86	1·05	3·37	6·15	·43
Warp A, mature ...	4·65	57·24	10·74	1·16	2·77	4·47	·49
Warp B...............	3·70	57·60	13·29	1·24	3·71	1·65	·46
Woburn	4·31	58·61	14·80	1·48	2·61	2·97	·20

POTATO SAMPLES OF THE SEASON 1904.

The season 1904 was in marked contrast to that of 1903. The latter with its cold wet summer and autumn was in every way abnormal, and disease was very widespread. The summer of 1904 was normal as regards rainfall and temperature, but owing to favourable vegetative conditions in late summer and autumn there was a good deal of 'second growth.'

Advantage was taken of the National Potato Society's variety trials at various centres, to secure samples of 'Up to Date' potatoes from seventeen localities.

The samples were subjected to a 'cooking test' of quality, the result of which, together with soil characteristics, is set out in Table VI. The samples are divided into three sets according to whether the 'blackening' was insignificant, moderate, or very marked. As in the 1903 samples discolouration was confined to the heel end of the tuber, and was most noticeable near the base.

TABLE VI.

Cooking test of potatoes from the crop of 1904.

Locality	Behaviour	Soil
A. 'Blackening' insignificant		
1. Reading College	No blackening in any part	Sandy soil on red gravel
2. Wallingford, Bucks....	Very slight darkening at heel end in individual tubers	....
3. Long Ashton, Somrst.		....
4. Warwick..................		Medium loam with gravel
5. Chelmsford		Heavy loam
B. Moderate 'blackening'		
6. Edmonton, Middlesex...	....	....
7. Cockle Park, Northumberland	....	Medium loam on mixed clay and sandstone
8. Wye College, Kent		....
9. Merton, Surrey............	....	Sandy brash
10. Orton, Wolverhampton	....	Medium sandy loam
C. Marked 'blackening'		
11. Holmes Chapel, Cheshr.	Badly discoloured, especially those steamed in skins	Moderately heavy loam
12. Halesowen, Stafford ...	,, and diseased	Stiff loam on clay loam
13. Droitwich	,, and some diseased	Sandy loam on New Red Sandstone
14. Evesham	,, more diseased	Clay loam on loamy clay
15. Kilnswick	,, badly diseased	Marly loam on marl
16. Creswell, Stoke............	,, ,, ,,	Medium loam on clay
17. Bath	Showed blackening worse than any other	Clay loam manured in part with ashes

EXPERIMENTS ON THE NATURE OF THE COLOURING MATTER.

It was observed that the freshly rasped material showed the same rapidity of surface change to red, brown and finally black, from both heel and seed halves of 'blackening' tubers and it was not less rapid from the best samples.

This excludes any connexion between 'blackening' and the action of the tyrosin splitting oxydase which causes the discolouration of the raw juice. That the discolouration is not due to physical causes was proved by drying and grinding a steamed piece of blackened tuber and comparing the hue of the powder with that from a similarly treated piece of normal colour. The powder from the blackened portion was grey in contrast with the creamy white of the other.

In the belief that the 'blackening' might be due to an oxidation of tannin derived from the splitting up of a glucoside during cooking,

TABLE VII. Dry matter and distribution of nitrogen determined on fresh material.

	Holmes Chapel, bad quality		Evesham, bad quality		Bath, bad quality		Reading, good quality		Cockle Park, good quality		Warwick, good quality	
	heel end	seed end	heel end	seed end	heel end	seed end	heel end	seed end	heel end	seed end	heel end	seed end
Dry matter	22·75	22·12	23·87	22·37	19·17	18·94	23·65	21·79	24·05	22·18	25·45	24·06
Nitrogen in parts per hundred of fresh substance:												
Total Nitrogen	·356	·336	·275	·276	·257	·265	·283	·268	·305	·285	·335	·310
Proteid Nitrogen	·162	·168	·132	·135	·120	·122	·118	·119	·130	·119	·135	·134
Non-proteid Nitrogen	·194	·168	·143	·141	·137	·143	·165	·149	·175	·166	·200	·176
Nitrogen in parts per hundred of dry matter:												
Total Nitrogen	1·565	1·519	1·152	1·190	1·341	1·399	1·196	1·230	1·268	1·285	1·316	1·288
Proteid Nitrogen	·712	·759	·553	·603	·626	·644	·499	·546	·540	·536	·530	·557
Non-proteid Nitrogen	·853	·760	·599	·587	·715	·755	·697	·684	·728	·749	·786	·731
Proteid Nitrogen in parts per hundred of total Nitrogen	45·5	50·0	48·0	48·9	46·7	46·2	41·8	44·4	42·6	41·9	40·3	43·2
Non-proteid Nitrogen in parts per hundred of total Nitrogen	54·5	50·0	52·0	51·1	53·3	53·8	58·2	55·6	57·4	58·1	59·7	56·8

Average distribution of nitrogen and dry matter in three bad and three good samples.

	Holmes Chapel, Evesham, Bath, bad quality		Reading, Cockle Park, Warwick, good quality	
	heel end	seed end	heel end	seed end
Dry matter	21·93	21·14	24·38	22·68
Nitrogen in parts per hundred of fresh substance:				
Total Nitrogen	·296	·292	·308	·288
Proteid Nitrogen	·138	·142	·128	·124
Non-proteid Nitrogen	·153	·150	·180	·164
Nitrogen in parts per hundred of dry matter:				
Total Nitrogen	1·353	1·369	1·260	1·268
Proteid Nitrogen	·630	·669	·523	·546
Non-proteid Nitrogen	·723	·700	·737	·722
Proteid Nitrogen in parts per hundred of total Nitrogen	46·7	48·4	41·6	43·2
Non-proteid Nitrogen in parts per hundred of total Nitrogen	53·3	51·6	58·4	56·8

some determinations of tannin were made both on air-dry and fresh materials. The material was thoroughly extracted either with cold water or hot alcohol, and the tannin determined by the indigo-permanganate-hide powder method. The amount found varied from ·04 to ·05 per cent. of the dry matter, and showed no difference in heel and seed end of 'blackening' samples. As no sample hitherto examined has shown really strong discolouration, no further attempt could be made to separate a colouring matter present in such infinitesimal quantity.

NITROGEN DETERMINATIONS.

In order to observe whether 'blackening' stood in any relation to the distribution of nitrogen in heel and seed end, determinations were made on the transverse halves of tubers from six samples. Three samples (Reading, Cockle Park, and Warwick) which cooked well were compared with three (Holmes Chapel, Evesham, and Bath) which discoloured badly. The results are shown in Table VII.

The figures do not indicate that the distribution of nitrogen in the two ends of 'blackening' samples differs from the relation found in good cooking samples. The dry matter determinations show a consistently greater amount in the heel end over the seed end, indicating a higher proportion of starch near the base of the potato.

The proportion of nitrogen and the ratio of proteid to non-proteid is much the same as in the 1903 samples.

The good samples, as in 1903, show a lower total nitrogen in dry

TABLE VIII.

Average results for dry matter, and nitrogen in dry matter for best and worst samples of two seasons.

	Six bad samples: North Belton, Warp A immature, Warp A mature, Holmes Chapel, Evesham, Bath	Six good samples: Thornton Loch, Woburn, Warp B, Reading College, Cockle Park, Warwick
Dry matter	21·16	22·46
Total Nitrogen	1·348	1·293
Proteid Nitrogen	·686	·535
Non-proteid Nitrogen	·662	·758
Proteid Nitrogen in parts per hundred of total Nitrogen	50·9	41·4
Non-proteid Nitrogen in parts per hundred of total Nitrogen	49·1	58·6

matter and a higher proportion of non-proteid nitrogen as compared with the bad cookers.

In Table VIII. figures are given showing the average dry matter and nitrogen in dry matter for the good and bad samples of both years. These results show a higher dry matter and lower total nitrogen in the good quality potatoes, and in a very marked manner, high non-proteid nitrogen and correspondingly low proteid nitrogen.

CONCLUSIONS.

The high ratio of amide to proteid nitrogen in the good quality potatoes examined is a point of much interest, but will require to be confirmed by many more analyses before being regarded as a general characteristic of good quality tubers. The uniformly higher proportion of dry matter in the heel halves of all the samples indicates that the basal end of the tuber is richer in starch than the seed end, although this relation may not hold for material which has started to sprout.

Indications seem to point to physical causes as exercising the greatest influence on quality, especially such as determine temperature and water supply. The mechanical analyses of the soils, for instance, show that the best potatoes came from soils which were neither lacking in the coarse particles (gravel, grit, and coarse sand) which ensure porosity and consequently warmth, nor in the finest materials (fine silt and 'Klay') which secure retention of water.

Climate, as affecting the distribution of seasonal rainfall and air temperature, must always play an important part in modifying the value of a soil for raising good quality potatoes, so that although a light soil of good physical composition (*e.g.* Thornton Loch) produces the best quality tubers in a moist climate, a heavy soil may do better in a warm dry climate. It is proposed to continue the work along lines suggested by the foregoing considerations, making use of pot experiments with regulated conditions of temperature and water supply in soils of varying texture.

As previously mentioned no sample as yet examined has shown really strong 'blackening,' so that nothing conclusive as regards that aspect of quality has been arrived at.

The investigation is being carried out at the Laboratory of the Lawes Agricultural Trust, to whom my best thanks are due, for the use of the laboratory and apparatus. I must express my sense of deep obligation to Mr A. D. Hall, M.A., Director of the Rothamsted Experimental Station, who suggested the investigation, and continued to give me valuable advice throughout.